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CONTENTS.

COMMONWEALTH OF AUSTRALIA

Advisory Council of Science and Industry

Recent Developments

IN THE

Organization of National Industrial Research Institutions

Memorandum prepared under the authority of the Chairman, THE RIGHT HON. W. M. HUGHES, P.C., M.P., and the Executive Committee of the Advisory Council

By

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Secretary.

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CONTENTS.

Recent Developments in the Organization of National Industrial Research Institutions.

By Gerald Lightfoot, M.A.

I.—INTRODUCTION.

1. Importance and Significance of the Movement.—The national importance and significance of the adequate development of scientific methods and, in particular, of their application to industry is now generally recognised throughout the world, and the last few years have seen a remarkable increase in the efforts made to stimulate the increase and application of scientific knowledge. In an address delivered before the British Science Guild in April, 1917, Lord Sydenham pointed out that the war has had the effect of turning a strong searchlight upon the innermost workings of national life. "Our weakness and our potential strength stand plainly revealed. We can see how severely we have suffered, and must still suffer, from our neglect in the past; and if we strive to ascertain causes, we cannot fail to reach the conclusion that our lack of appreciation of all that science—using that term in its broadest sense—could have conferred upon us lies at the root of many present difficulties."*

In addition to the difficulties which have arisen in the course of the war as a result of absence of scientific knowledge and habits of thought, there is another side which cannot be neglected. The question of reconstruction after the war is now occupying the minds of all thoughtful persons. National prosperity and financial stability can be maintained after the war only by increased productivity and trade. This implies the necessity for the application of the results of scientific research in the creation of new industries, processes, and methods, and the economic development of those which now exist.

Among the European nations there is a great awakening to the national value of scientific research. The British Government has recently created a new Department of Scientific and Industrial Research, with a fund of over £1,000,000 at its disposal; a conjoint Board of Scientific Societies has been established at the instance of the Royal Society; an important and influential Committee on the Neglect of Science has taken up the question of scientific knowledge and training in the Public Services, at Oxford and Cambridge, and in the public schools; an Education Reform Council, comprising representatives of science, industry, and commerce as well as of education has been appointed; while various other organizations have taken up one or other branches of the subject of the development of science and its co-ordination with industry, education, and administration. In France a new national institution for scientific research on a large scale is projected as a result of action taken by the Paris Academy of Sciences. In Canada a Research Council has been established on a permanent basis by the Dominion Government to take charge of matters affecting scientific and industrial research in Canada, and to advise on questions of scientific and technological

* *See* Eleventh Annual Report of the British Science Guild, London, 1917, p. 66.

methods affecting the expansion of Canadian industries or the utilization of the natural resources of Canada. In the United States a National Research Council has been established at the instance of the President, for the purpose of developing and bringing into co-operation existing governmental, educational, industrial, and other research organizations. In Japan a National Research Institute is being established on a large scale, involving the expenditure of over £500,000. In New Zealand and South Africa national research organizations are also being established. In Australia the importance of applying science to the industries of the country has been recognised by the Commonwealth Government, through the initiative action of the Prime Minister, the Rt. Hon. W. M. Hughes, P.C., M.P., by the establishment, in 1916, of a temporary Advisory Council of Science and Industry, which was intended to prepare the way for a permanent Institute of Science and Industry.

The illustrations cited above serve to show that throughout the world there is a recognition of the fact that the development of national resources is dependent on scientific methods and research, and they indicate also the path that must be followed if our industries are to be so mobilized and developed that they may be prepared adequately to take their part in the great industrial struggle which will follow the termination of the war.

2. Scope of Report.—Information regarding post-war developments in the establishments of national industrial research institutions is contained in a variety of reports and documents which are not ordinarily accessible to the general reader. As the whole movement is one which has arisen out of the war, and which is likely to have an important and far-reaching influence on national development and reconstruction, it is believed that a brief statement of the position will be of value and interest in Australia at the present time.

This report deals only with organizations which are of a national or semi-national character. It is well known that, in addition to these national undertakings, there has been considerable activity during the last year or two, in various parts of the world, in the initiation and development of research work by universities and technical institutions and by manufacturing and other industrial enterprises.

II.—THE UNITED KINGDOM.

1. The Department of Scientific and Industrial Research.—In the United Kingdom a separate Department of Scientific and Industrial Research has been established. Its general administration is in the hands of a small Committee of the Privy Council consisting of nine members of the Government, but its work is directed by an Advisory Council of eight members of distinction in science and of eminence in the industries. One of the members of the Advisory Council is the permanent Administrative Chairman. In addition to the Secretary, the Department has a staff of 32 officers, several of whom possess high scientific and technical qualifications. An important feature of the scheme of organization is the method by which other scientific and technical Departments of the Government are brought into touch with the Department of Scientific and Industrial Research. Each such Department has power to appoint an assessor to the Advisory Council. These assessors are provided in advance with information as to the matters on the agenda paper at meetings of the Council; they can attend and join in the deliberations, but have no vote. Twenty-one assessors have been appointed.*

The work of the Department is carried out largely through Standing and Special Committees, the members of which are selected, both on the scientific and industrial side, from the most eminent men available in the respective subjects. In addition to the annual appropriations by Parliament for the work of the Department, which amounted to £38,000 in the financial year 1916–17, the Government has placed a sum of £1,000,000 at the disposal of the Department to enable it to co-operate with the industries of the country in the foundation and maintenance of approved Associations for Research during the next five years or so. The annual vote is intended to cover (*a*) the cost of those researches which will not be undertaken by the Research Associations; (*b*) grants to individual research workers; and (*c*) costs of administration. It should be observed, however, that these sums have been provided by the British Government for industrial research in connexion with secondary industries only. Rural industries are dealt with by the Agricultural Development Commission, which was established in 1909 with a grant of £500,000 per annum for the purpose of developing agricultural industries by scientific research, and by instruction and experiments in agriculture.

(i) *Industrial Research Associations.* Contributions from the fund of £1,000,000 are made to the income of approved associations, varying in amount according to circumstances and with a normal maximum of pound for pound, though in exceptional cases this limit may be exceeded. The contributions made by industrial establishments are recognised as business costs, and are not subject to Income or Excess Profits taxes. The Government contribution is made for a period not exceeding five years, but may be extended. It is anticipated that when the Research Associations are once fairly launched the need for direct subsidy by the State will disappear.

The benefits derived by a firm contributing to a Research Association may be briefly summarized as follows:—

(*a*) Regular service of summarized technical information from both British and foreign sources.

(*b*) Right to receive answers to questions on technical or scientific matters.

(*c*) Right to use patents or secret processes resulting from researches undertaken by an Association.

(*d*) Right to ask for a specific research to be undertaken for its sole benefit at cost price.

The fund for each industry is controlled by a Board appointed mainly by the contributing firms. It is obvious that capital, management, and science must have suitable representation, but importance is attached also to the representation of the workers in the industries concerned. In this connexion reference is made in the last report of the Advisory Council to the proposals contained in the Interim Report of the Sub-Committee of the Reconstruction

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* *See* Report of the Committee of the Privy Council for Scientific and Industrial Research, London, 1916–17.

Committee on Relations between Employers and Employees (Cd. 8606), commonly known as the Whitley Report, which advocates the establishment of Standing Joint Industrial Councils. It is proposed in the latter Report that the National Councils should have power to allocate to District Councils the following questions :—

(*a*) Industrial Research and the full utilization of its results ; the provision of facilities for the full consideration and utilization of inventions and improvements designed by work-people, and for the adequate safeguarding of the rights of the designers of such improvements.

(*b*) Improvements of processes, machinery, and organization, and appropriate questions relating to management and the examination of industrial experiments, with special reference to co-operation in carrying new ideas into effect and full consideration of the work-people's point of view in relation to them.

The scheme for the formation of Industrial Research Associations has already met with considerable success. The associations established include Cotton Manufacturers, Woollen and Worsted Manufacturers, Flax Spinners and Weavers, Shale-oil Industry, Photographic Manufacturers, Electrical Engineers, Aircraft Constructors, Shipbuilders, Iron Puddlers, Pianoforte Manufacturers, Master Printers, the Cocoa Industry, and Papermakers. Associations receiving grants must be approved and registered by the Board of Trade, and existing organizations are utilized, if practicable.

(ii) *Standing and Special Committees.*—Up to the 30th June, 1917, Committees had been appointed on Engineering, Metallurgy, Mining, Glass and Optical Instruments, Mine Rescue Apparatus, Abrasives and Polishing Powders, Lubricants, and Zinc and Copper. A Fuel Research Board has been appointed as a part of the Department to investigate the whole question of the production and utilization of fuel in the United Kingdom both for industrial and domestic purposes. A considerable number of systematic investigations have also been initiated by the Department in connexion with existing institutions, such as the Concrete Institute, the National Physical Laboratory, the Research Institute for Glass, the Institute of Technical Optics, and the Imperial College of Science and Technology.

(iii) *Other Investigations.*—In addition to the more systematic investigations referred to above, the Department has either aided or initiated a considerable number of important investigations. These include researches into Light Alloys (in co-operation with the Institution of Mechanical Engineers and the National Physical Laboratory), the Corrosion of Non-ferrous Metals (in co-operation with the Institute of Metals and the University of Liverpool), Refractories (in co-operation with the School of Science and Technology at Stoke), Hard Porcelain (in co-operation with the Staffordshire Pottery Manufacturers' Association), Hardness Tests for Journals and Pins, the Flow of Steam through nozzles (of great importance to turbine manufacturers), the Heating of Buried Cables and Insulating Oils (in co-operation with the Institute of Electrical Engineers), High-speed Tool Steel (in co-operation with the Manchester Association of Engineers), the Recovery of Tin and Tungsten, the Degumming of Silk (in co-operation with the Silk Association of Great Britain), the Deterioration of Structures in sea water (in co-operation with the Institute of Civil Engineers), Steam Superheaters Cellulose, and a series of researches into various problems of the dyeing trade.

It is important to observe also that a considerable number of grants have been made to research workers. For the year 1917–18 a sum of £6,000 was set aside for this purpose, and in allocating the grants no distinction is made as to whether the researches are of a purely scientific or an industrial nature.

(iv) *Work carried out.*—It is not practicable within the limits of this pamphlet to furnish an adequate account of the work accomplished by the Department, or of the valuable results already obtained from the researches initiated by it. One or two examples may, however, be given. For instance, the researches into the recovery of tin have already produced results which will give a 5 per cent. improvement in the amount of tin recovered in Cornish mines, an economy that will add £30,000 a year to their receipts. The investigations into high-speed steel have resulted in the standardization of heat treatment in a manner which has been of great value to the Admiralty in the manufacture of certain implements of war. The tests for journals and pins have revealed the fact that the methods previously adopted are not a safe guide to the relative resistances to wear. In the hard porcelain experiments a cheap and satisfactory ware has been produced and a new glaze developed. In connexion with light alloys, very valuable work has been done in connexion with the manufacture of alloys of aluminium for air-ship construction and other purposes. In the glass and optical work results of the highest importance have already been obtained. Professor Jackson has succeeded in defining the composition of the mixtures necessary for the production of several glasses hitherto manufactured exclusively at Jena, and three completely new glasses, with properties hitherto unattainable, have been discovered.

2. The National Physical Laboratory.—There is one class of scientific problems of great importance to industry not susceptible of treatment by associations or committees for research, viz., the determination of constants and standards, whether physical, chemical, or bacteriological, and the accurate testing of manufactured products in the interests both of producer and consumer. The importance of this work and of the research which it entails has long been recognised in certain countries, notably America and Germany, and is certain to grow rapidly in the near future. Experience has shown that if this work is to be adequately performed it must be undertaken by the State itself, or at least under the control of the State. The development of this class of work began in Germany, where there is a number of national laboratories which have achieved great success and international importance. In the United States the Bureau of Standards, which is financed by the Government with a liberality which completely eclipses that in any other country, has developed into an institution of great size and of immense importance and utility both to science and to the industries of the country.

(i) *Organization.*—The National Physical Laboratory near London was originally established on a comparatively small scale in 1901 under the control of the Royal Society, but an arrangement was made in 1917 under which the

Department of Scientific and Industrial Research is now financially responsible for the maintenance of the Laboratory. The scientific management of the Laboratory remains in the hands of a General Board and Executive Committee. On the latter the leading scientific and technical societies are represented, as well as certain Government Departments, so that the members of the Committee comprise leading experts in most branches of applied science.

Any account which can be given of the Laboratory must relate practically to the state of affairs as they existed before the war. At the present time the activities of the Laboratory are very largely absorbed by work in connexion with the war, and since these are necessarily of a confidential nature no reference to them can be made here.

Before the war the annual grant made by the Government to the National Physical Laboratory amounted only to £7,000. The last balance-sheet issued before the war showed that the total revenue was £40,000, of which about £30,000 was earned in the form of fees for testing and other work carried out for both Government Departments and private firms and individuals. In addition, technical institutions contributed to the revenue either by donations or by grants in aid of some definite scheme of research. The total capital expenditure on the Laboratory up to March, 1914, was approximately £156,000.

(ii) *Departments.*—The Laboratory itself is divided into four main departments dealing with physics, engineering, metallurgy and metallurgical chemistry, and the naval experimental tank, respectively.* In addition to the Director, superintendents, and principal assistants, there is a large staff of scientific assistants, trained "observers," and skilled workmen.

(*a*) In the Physics Department there is, firstly, the section dealing with various aspects of electricity. This section includes the determination of electrical units, the testing of electrical machinery and appliances of every kind. The second division is that known as Thermometry, which includes the testing and standardization of all kinds of thermometers and pyrometers. The third section is devoted to optics, and deals principally with the testing of optical instruments of all kinds, including nautical and surveying instruments, as well as telescopes, binoculars, periscopes, &c. The fourth division is devoted to pure measurement, called Metrology. This division is concerned with measurements of length, volume, and mass. Extreme accuracy of measurement has attained the highest importance in modern engineering, and the work of this section entails a large amount of research of great delicacy.

(*b*) The Engineering Department comprises what are practically four sections devoted, respectively, to the testing of materials, the testing and standardization of engineering apparatus, appliances and machinery, the testing and investigation of road materials and roads, and aeronautics. This Department has devoted itself to an exhaustive study of various methods of testing and to certain special problems which have been presented for study from outside practice. These investigations have led to results of the highest importance to the engineering and other industries. The work

* *See* "The National Physical Laboratory, Its Work and Aims," by D. Rosenhain, B.A., B.Sc., F.R.S., *Journal of the West of Scotland Iron and Steel Institute*, 1915–16.

carried out in regard to the testing of machines, apparatus, and appliances such as the testing of pressure gauges, the calibration of testing machines, &c., is also of fundamental importance. The work of the aeronautical section of the Department has also achieved results of the greatest value.

(*c*) The Department for Metallurgy and Metallurgical Chemistry deals broadly with five distinct sections; firstly, physical metallurgy and metallography, including the whole subject of the thermal and mechanical treatment of metals and alloys. Another section deals with the chemical analyses of metals, while there is a smaller section devoted to general chemical questions, chiefly those arising out of other work undertaken either in the Department or elsewhere in the Laboratory. The fourth section deals with the chemistry of aeronautics, while the fifth section deals with tests and research work on glass, primarily for optical and scientific purposes.

(*d*) The Naval Tank is devoted to experimental work on scale-models of vessels, and is an essential feature in the adequate development of naval architecture. Both systematic research and tests for practical purposes are carried out. Recently much attention has necessarily been given to special matters, such, for example, as the head-resistance and stability of seaplane floats.

(iii) *Importance of Work.*—The work carried out by the National Physical Laboratory and similar institutions in other countries is not only of fundamental importance to Government Departments and scientific institutions and to the prosecution of the war, but is highly beneficial, firstly, to consumers—in bringing about improvements in quality—and, secondly, to producers—in the adoption of improved standard types and qualities, and of scientific methods of control of temperatures, pressures, measurements of space and time, chemical processes and other technical factors which determine the amount and quality of the output of secondary industries, and upon which industrial efficiency is largely dependent.

3. The Board of Scientific Societies.—This Board was established at the instance of the Royal Society, and consists of representatives of 27 scientific, technical, learned, and professional associations. It was established for the following purposes:—

- (i) Promoting the co-operation of those interested in pure or applied science.
- (ii) Supplying a means whereby the scientific opinion of the country may, on matters relating to science, industry, and education, find effective expression.
- (iii) Taking action to promote the application of science to industries and to the service of the nation.
- (iv) Discussing scientific questions in which international co-operation seems advisable.

Sub-committees have been appointed to deal with the following matters:—(*a*) International Catalogue of Scientific Literature; (*b*) Application of Science to Agriculture; (*c*) National Instruction in Technical Optics; (*d*) Education; (*e*) Prevention of Overlapping among Scientific Societies; (*f*) Metric System; (*g*) Anthropological Survey; (*h*) Iron-ore; (*i*) Water-power of the British Empire; (*j*) Timber for Aeroplane Construction.

These Sub-committees have carried out valuable work of national, and in some cases of Imperial, importance, and nearly all of them have already presented either Final or Interim Reports.

4. The "Neglect of Science" Movement.—For many years before the war attention had been directed in England to what is alleged to be a cause of danger and weakness in national organization, viz., the lack of knowledge on the part of legislators and administrative officials of "physical science," by which is meant the ascertained facts and principles of mechanics, chemistry, physics, biology, geography, and geology. It is stated that the same defect runs through almost all the public Departments of the Civil Service, that it is nearly universal in the House of Commons, and that it is shared by the general public, including a large proportion of those engaged in industrial and commercial enterprise.

As a result of the war, which is stated to have revealed numerous instances of want of understanding of scientific facts on the part of administrative and other public officers, an influential and representative meeting was held in London in May, 1916, to consider what action should be taken to remedy this state of affairs. It was considered that the only effective way of obtaining a reasonable appreciation of scientific method in the community generally was the passing of an Act directing the Civil Service Commissioners and the Army Examination Board to give an adequate share of marks in competitive examinations to natural science subjects. It was thought that in this way "science would rise in our schools to a proper position and gain the respect necessary for national welfare. A popular appreciation and understanding of science would begin to develop and our officials of all kinds, no less than Members of Parliament, would come to be as much ashamed of ignorance of the commonplaces of science as they would now be if found guilty of bad spelling and arithmetic."

At the meeting the importance of encouraging the study of the natural sciences and thereby increasing the efficiency of the Public Service was strongly emphasized. It was considered that the desired change in the attitude of the schools and colleges towards the teaching of science and in imbuing a general knowledge and appreciation of scientific methods could be brought about only by the Government assigning capital importance to scientific subjects in the examinations for the Public Service. Information is not available regarding the results of the movement, but it is understood that the proposals are receiving the consideration of the Government.

5. Council for organizing British Engineering Industry.—The Manchester Engineers' Club, in co-operation with the British Engineers' Association, have established a scheme for the organization of the British engineering industry on a national basis. The scheme provides for the federation of manufacturing engineers for purposes which include education and research. The federation is to co-operate with governing bodies of schools and colleges and other educational authorities in providing a satisfactory system for educating engineers; with Universities and Technical Colleges in testing and research; and with the Department of Scientific and Industrial Research in conducting a central research institution specially equipped for investigations with which existing research laboratories are unable to cope.

III.—CANADA.

1. The Canadian Industrial Research Department.—In Canada a national organization for scientific and industrial research was established by an Act passed by the Dominion Parliament in August, 1917. The scheme is similar to that adopted in England, that is to say, a new Department has been created consisting of a Sub-committee of the Privy Council of Canada and an Advisory Council for Scientific and Industrial Research, consisting of not more than eleven members of whom one is the permanent salaried Administrative Chairman.

The Council has charge of all matters affecting scientific and industrial research in Canada assigned to it by the Sub-committee of the Privy Council, and advises on questions of scientific and technological methods affecting the expansion of Canadian industries and the utilization of the natural resources of Canada. A sum of over £18,000 was appropriated by Parliament for the work of the Council during the first financial year. The Council is working in co-operation with such bodies as the Canadian Manufacturers' Association, the Canadian Society of Civil Engineers, the Canadian Mining Institute, and the Society of Chemical Industry.

The work in progress or projected includes a comprehensive industrial census, the training and utilization in industrial establishments of "efficiency experts," the creation of technical laboratories under State co-operation at the great industrial centres to give free help to manufacturers in solving their problems, the utilization and development of the latent fuel resources particularly of the Prairie Provinces, and the preservation of the diminishing timber resources of Eastern Canada. The collection of preliminary information regarding laboratories and institutions available for research work, and their *personnel*, raw materials required, by-products worked and scientific and technical problems affecting the progress and development of industries, has been carried out on lines similar to those adopted by the Commonwealth Advisory Council of Science and Industry.

Provision has been made for the award of a number of studentships and fellowships in Universities and Technical Schools, to be given to men who have completed their regular course of study and have displayed a special aptitude for scientific research. These will enable such men to pursue a course of advanced work for a further period. Arrangements will also be made by which men after graduation will be placed in one or other of the great manufacturing establishments of the Dominion, where they will continue their training under the conditions of actual commercial practice.

In order to furnish direct assistance to the manufacturing industries of Canada at once, Industrial Research Bureaux are to be established at certain of the great industrial centres of the Dominion, such as Toronto, Montreal, and Winnipeg, in co-operation with the Provincial Government or other bodies. At these Bureaux a complete set of technical magazines and trade journals will be kept, and technical staffs, provided with suitable and properly equipped laboratories, will assist the manufacturers of the district in solving problems which present themselves in their factories or works. A beginning has already been made by the establishment of a Research Bureau at Montreal.

2. The Forest Products Laboratories of Canada.—These Laboratories were established by the Dominion Government in co-operation with the McGill University of Montreal. Though some work had been carried out before the war, the laboratories were not officially opened until the end of 1915. Before that date the work of the Forestry Branch had been confined almost entirely to operations in the field, such as fire-prevention and reafforestation. But it was felt that if the forest wealth of the country was to be adequately developed it was necessary to follow the timber further towards its ultimate utilization and to carry out scientific investigations with the object of preventing as far as possible the enormous waste which occurs between the time when the timber leaves the forest and the time it reaches the ultimate consumer.

Before establishing the laboratories an exhaustive study was made of the methods adopted at the U.S.A. Forest Products Laboratory at Madison, Wisconsin.* The work of the laboratories is under the direction of the Forestry Branch, but an Advisory Committee consisting of three professors of the University and four prominent business men interested in forest products, meets from time to time and advises as to the general lines of the investigations to be undertaken. The scope of work covers all products derived from wood, ranging from railway sleepers and heavy timbers, fine lumber and furniture material to pulp and paper, distillation products such as turpentine, wood oils, acetone, wood alcohol and other materials into which wood may be chemically transformed such as cattle food, ethyl alcohol, artificial silk, and nitro-cellulose.

The investigations are carried out in four main divisions. The division of timber physics comprises such work as the micro-structure of wood and changes caused by moisture and, in general, all botanical and physical properties of wood other than mechanical strength. The division of timber tests covers the work of determining the mechanical strength of wood. The division of preservation deals with investigations relating to the decay of wood and the prevention of that decay by preservative treatment. The division of pulp and paper, which is perhaps the most important, comprises investigations relating to the use of wood as a paper-making material.

The laboratories have been equipped at a total cost of about £8,000. This expenditure has been paid out of the annual appropriations by the Government, which up to the 31st March, 1917, amounted to £38,000, including an initial vote of £2,000 in 1913, and an annual vote of £12,000 since that time. The staff consists of 36 officers, the majority of whom possess special scientific or technical qualifications. It is anticipated that a branch laboratory will be established in British Columbia to deal especially with timber for aeroplane construction.

3. The Natural Resources Survey of Canada.—In 1916, the Canadian Pacific Railway instituted a survey of the natural resources of the Dominion with a view to their development and mobilization. Although initiated by the C.P.R. and supported by that company, it was arranged that the work

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* An account of the organization and work of this Laboratory may be found in the Memorandum on the Organization of Scientific Research Institutions in the U.S.A., by Gerald Lightfoot, Commonwealth Parliamentary Paper, No. 852, 1916.

of the survey should not be conducted in the interests of any individual corporation or person, but impartially for the general benefit of the community, and with the purpose of advancing the industrial development and prosperity of the Dominion.

The initial object of the survey was to recast into quickly available form the immense mass of information regarding Canadian resources contained in Government publications, scientific and technical journals, corporation records and reports of individuals, and to make a census of scientific and technical men with particular reference to their specialized lines of study and research, and to catalogue and classify the technical libraries and research facilities of the country. The plan of the survey then provided for the prosecution of industrial research on lines selected for their promise of yielding results of broad general benefit or of immediate advantage.

The work of conducting the survey was placed in the hands of a private corporation, and a large amount of valuable work was carried out in that way. Shortly after the creation by the Dominion Government of the Advisory Council for Scientific and Industrial Research the offer of the corporation to hand over to the Council all the data accumulated was accepted, and it is understood that the work is now being pursued under the auspices of the Advisory Council.

IV.—AUSTRALIA.

1. The Commonwealth Advisory Council of Science and Industry.—The Commonwealth Advisory Council of Science and Industry was established in March, 1916, for the purpose of preparing the ground for the proposed permanent Institute of Science and Industry, and of exercising in a preliminary way the functions that will belong to the future Institute. The Advisory Council itself has held only three meetings, but a large amount of work has been carried out by the Executive Committee, the State Committees, and by Special Committees which have been appointed either to inquire into particular matters or to carry out actual experimental work. An account of the work carried out by the Council is given in the Report of the Executive Committee up to the 30th June, 1917, but since that time considerable progress has been made. The work may be summarized under the following heads :—(i) Preliminary work ; (ii) Systematic inquiries and investigations under the control of Special and Standing Committees ; (iii) Conferences ; (iv) Miscellaneous.

(i) *Preliminary Work.*—This work has been largely completed and comprises :—

A. A register or census—(*a*) of Australian industries, their distribution and importance ; (*b*) of problems connected with them ; (*c*) of the equipment and *personnel* of laboratories throughout the Commonwealth available for industrial scientific research ; (*d*) of research work in actual progress in laboratories and at Government experimental farms ; (*e*) of the facilities available for training scientific investigators.

B. The establishment of relations with other authorities, such as State Governments, scientific and technical Departments, Universities, Technical Colleges, Scientific Societies and Associations and Committees representing the pastoral, agricultural, manufacturing, and other industries.

C. The encouragement and co-ordination of researches already in progress.

(ii) *Special Committees.*—After making full inquiries and collecting all available information from reports and experts on any special question, the Executive has adopted the plan of appointing in each approved case a small Special Committee either to report further or to carry out actual experimental investigations. In forming these committees, special attention has been paid to securing adequate representation on the industrial as well as the scientific side. Twenty-seven Special Committees have been appointed, and most of them have issued either Interim or Final Reports. An account of the work carried out by these committees up to the 30th June, 1917, appears in the last report of the Executive Committee. In cases where the investigations have been completed or are sufficiently advanced for publication the results have been made available in the form of Bulletins, of which six have been published. Others are in course of preparation.

The following is a list of the Special Committees established up to April, 1918:—

List of Special Committees established up to April, 1918.

1. Ferro Alloys.
2. Mode of Occurrence of Gold in Quartz.
3. Alunite.
4. Yeasts and Breadmaking.
5. Damage by Insects to Grain in Store.
6. Purification of Damaged Wheat by Lime.
7. Electrical Sterilization of Milk.
8. Tanning Methods in New South Wales.
9. Utilization of Mangrove Bark for Tanning (Queensland).
10. Utilization of Redgum for Tanning (Western Australia).
11. Means of Transmission of Worm Nodule Parasite.
12. Control of Sparrow Pest.
13. Alcohol Fuel and Engines.
14. Posidonia Fibre.
15. Grass Tree Resin.
16. Development of Mechanical Cotton Picker.
17. Utilization of Phosphatic Rocks.
18. Life History of the Cattle Tick.
19. Substitutes for Tin Plate.
20. Commercial Utilization of Kelp.
21. Blow-fly Pest in Queensland.
22. Cold Storage Problems.
23. Tuberculosis in Stock.
24. Native Grasses and Fodder Plants.
25. Bye-products of Wool-Scouring Industry.
26. Nitrogen Requirements of Australia.
27. Classification of Imports of Chemicals.

The members of these Special Committees act in a purely honorary capacity. Grants are made from the funds of the Advisory Council for the purchase of apparatus and equipment, and for the reimbursement of travelling and out-of-pocket expenses of the members of the Committees whilst engaged on the work. In a number of cases salaried investigators and assistants are employed to give their whole time to the work under the direction of the several Committees.

(iii) *Standing and other Investigational Committees.*—In cases where the investigational work is of a permanent or prolonged nature, Standing Committees have been established. These include the Chemicals Committee, the Committee inquiring into the marine biological economics of tropical Australia, the Committee on the metric system and decimal coinage, and the Seed Improvement Committee which has been established to undertake the examination, comparison and classification of different varieties of cereals.

In addition certain investigations are being conducted in co-operation with Committees established by other institutions, such as the Society of Chemical Industry of Victoria, the New South Wales Pastoral Committee on the Blow-fly Pest, and the Electrical Association of Australia.

In the case of the flax industry a Committee has been established under the War Precautions Act to control and develop the industry. It is anticipated that the action taken by the Advisory Council in this matter alone will result during the present season in an increase in wealth produced, which will pay several times over for the total expenditure on the work of the Advisory Council from the date of its inception.

There are a considerable number of other matters of high importance under investigation but which have not yet reached the stage at which they can be referred for systematic work by committees of experts, or which cannot be dealt with adequately until the permanent Institute is established. These include paper-pulp, the prickly-pear pest, the control and eradication of certain weed-pests, destructive distillation of hard-woods, and other problems affecting forest products, ceramics, enamels and glazes, diseases of stock, the introduction of new plants, and cultivation in arid and semi-arid regions.

(iv) *Conferences.*—An Inter-State conference of agricultural scientists was held under the auspices of the Advisory Council towards the end of 1917, and has already been productive of results of much value. A conference was held in Brisbane in January, 1918, to devise a scheme of co-operative action between the Commonwealth and New South Wales and Queensland State Governments for the repression, with a view to the eradication, of the cattle-tick pest. The report of this Conference has been published as Commonwealth Parliamentary Paper No. 40, 1917-18. The Advisory Council was represented at the Inter-State Forestry Conference held at Perth in 1917, and as a result is taking action for the compilation of data on a uniform basis on the important matter of forestry. This is one of the first steps necessary towards the establishment of a Forest Products Laboratory. Other conferences are projected.

(v) *Miscellaneous.*—A large number of inquiries and investigations of a very varied nature have also been made. Some of these have reached finality, others are still receiving attention. They have arisen largely through inquiries made by persons engaged in industries for advice on scientific and technical matters and by inventors or discoverers of new processes or raw materials. At present they fall into no considered plan, but it is probable that many of those which are still receiving attention will find their place later in some co-ordinated scheme of work under the permanent Institute. With the staff and funds at the disposal of the temporary organization it has not been practicable to undertake systematic investigations into those of them which the Executive Committee consider require such investigation.

2. The proposed Permanent Institute of Science and Industry.—The outline of a scheme for the organization of the proposed permanent Institute was drafted in January, 1916, and was approved by the Commonwealth Government. A detailed scheme has since been drafted and published. It was approved at a meeting of the whole Advisory Council held in July, 1917, and its general principles have been accepted by the Commonwealth Government.

(i) *Organization.*—The main lines of the scheme of organization are as follows :—

(*a*) That the control of the Institute should be placed in the hands of three highly qualified salaried Directors.

(*b*) That of the three Directors, one should be an expert business and financial man with ability in organization; the other two should be chosen mainly on account of scientific attainments and wide experience.

(*c*) That an Advisory Council representing science and the principal primary and secondary industries be appointed in each State, who shall advise the Directors in respect to the affairs of the Institute. The Directors are to meet each Advisory Council at least once a year.

(*d*) That the staff of the Institute should be appointed by the Governor-General on the recommendation of the Directors and should be excepted from the operation of the Public Service Act.

(ii) *General Nature of Work to be Undertaken.*—The general nature of the work which it is recommended should be carried out during the first years of the development of the permanent Institute is indicated in the published Report under the following headings :—

(*a*) Research work, including agricultural and pastoral matters, forestry, mining, metallurgy, &c., and manufacturing industries.

(*b*) Standardization work.

(*c*) The establishment of a Bureau of Information.

(iii) *National Laboratories.*—The Advisory Council is of the opinion that, while existing laboratories should be utilized as far as suitable and available, in order to provide adequate facilities for the research work which is necessary, national laboratories should be established for investigations into the following branches of science and technology :—

(*a*) Plant Industry (especially in relation to cultivation in arid or semi-arid regions, and to the control of weed pests).

(*b*) Animal Industry (especially in connexion with the control of pests and diseases).

(*c*) Industrial Chemistry and Metallurgy (technological research).

(*d*) Industrial Standards (scientific instruments, electrical apparatus, and materials used in industry).

(*e*) Forest Products (especially preservation and seasoning of timbers, utilization of waste wood, &c.).

At the outset it will not be desirable, even if possible, to erect complete laboratories and equip them fully; but it is recommended that sufficient provision should be made as soon as possible for the more pressing work in each of the above departments, with arrangements for extension later on.

(iv) *Urgency for Establishment of Permanent Institute.*—It was pointed out in the last Report of the Executive Committee that the work for which the temporary organization was established had been largely completed. The Advisory Council expressed the view in the Report of its meeting in July, 1917, that the immediate establishment of the permanent Institute is a matter of urgency, as the financial and executive powers of the temporary body are wholly inadequate to the purposes in view. Moreover, the various State Governments are anxious to undertake industrial research work with a view to developing industries of importance to their respective States, and in many cases the State Governments are holding their hands pending the organization of the Commonwealth enterprise. In some instances the State Governments intend to proceed on their own account unless the Commonwealth proposals are quickly materialized. Such action will limit the usefulness of the Institute, and prevent a favourable opportunity being availed of to obtain the co-operative assistance of the State Governments. On these grounds the Advisory Council recommended in July, 1917, that the permanent Institute should be established at once.

V.—NEW ZEALAND.

Several proposals for the establishment of a national organization in New Zealand for scientific and industrial research have been made, and it is understood that the whole matter is now receiving the consideration of the Government. Under the National Efficiency Act, one of the duties of the Board which was established was to enquire into the necessity for scientific research with respect to the maintenance, development, or establishment of industries. The Efficiency Board requested the New Zealand Institute to frame a scheme for consideration, and the Institute has established an Industrial Research Committee for that purpose.

The General Council of Education has drawn up a scheme for the adaptation of the educational system of the Dominion to the development of its resources. The scheme provides for the establishment of a National Advisory Council on Research for the following purposes:—

(*a*) To consider and allot to the proper persons for investigation all proposals for specific researches.

(*b*) To consider problems affecting particular industries, and to determine the lines for research.

(*c*) To award National Research Fellowships and Scholarships.

(*d*) To advise the General Council of Education as to the lines along which there could be brought about a general improvement in scientific education with a view to the training of experts and the better appreciation of the aims and advantages of science on the part of producers and the general body of citizens.

The Science and Industry Committee of the Wellington Philosophical Society has also recommended the adoption of a scheme for the application of science to industry. This scheme advocates the creation of a Board of Science and Industry, with a Minister for Science and Industry as Chairman, together with a National Advisory Council on Research and four or more local Advisory Committees.*

VI.—SOUTH AFRICA.

In October, 1916, the South African Government appointed an Industries Advisory Board, the members of which hold office for three years, and are almost entirely business men representative of commerce, manufactures, and labour. In February, 1917, this Advisory Board recommended the appointment of a Scientific and Technical Advisory Committee to deal with all scientific and technical matters and questions of research referred to them by the Industries Advisory Board. The Government accordingly constituted a Committee of ten members representing science and industry, and the following is a brief outline of the work which the Committee has undertaken:—

(*a*) In addition to providing for industrial research, the co-ordination as far as possible of all industrial investigations and research in South Africa, and the collection and dissemination of data emanating therefrom.

(*b*) Co-ordination with other Government Departments and with similar Departments of the United Kingdom and the Dominions to obtain information already available, to avoid overlapping, and to take advantage of facilities for research not available in this country. The acquisition and utilization in arts and manufactures of knowledge already in existence in countries which are more highly developed than South Africa.

(*c*) Carrying out an economic survey of the natural resources of South Africa, and the furnishing of advice in regard to the best methods of utilizing such resources.

(*d*) The furnishing of advice in regard to the best methods of attacking industrial problems in the improvement of facilities for manufacture in suitable localities.

(*e*) The co-ordination of various industries to obtain combined results, and the exchange between user and manufacturer of manufacturing improvements and operating experience.

(*f*) The standardization of scientific and industrial qualities affecting the efficiency of production and the accuracy of statistics.

(*g*) Educational work, such as lecturing, the publication of technical information, and the establishment of technical museums in suitable localities.

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* *See* N.Z. Parliamentary Paper H. 47, 1917, pp. 6–9.

VII.—UNITED STATES OF AMERICA.

The facilities provided in the United States for industrial scientific research are probably better organized and more munificently endowed and subsidized than in any other country. A description of the work and organization of the more important national and other scientific bureaux and institutions may be found in a Memorandum on the Organization of Scientific Research Institutions in the U.S.A., by Gerald Lightfoot, published as Commonwealth Parliamentary Paper No. 352, 1916.* As a result of the war it was recognised in America that there was a lack of organization and co-ordination among the various institutions, and that it would be profitable to devise some scheme to avoid overlapping, and to secure the proper distribution of effort over the whole field of scientific research in connexion with national defence and industrial efficiency.

In response to a request from the President of the United States, the National Academy of Sciences has organized a National Research Council, which is composed of leading American investigators and technologists representing the Army, Navy, Smithsonian Institution, and various scientific bureaux of the Government, educational institutions and research endowments, and the research divisions of industrial and manufacturing establishments. In order to secure a thoroughly representative body, the members of the Council were chosen in consultation with the presidents of the more important scientific, technical, and learned associations and societies of the country. The object of the Council is to bring into co-operation existing Governmental, educational, industrial, and other research organizations with a view to securing industrial scientific research, the increased use of scientific methods in the development of American industries, and in strengthening the national defence and such other applications of science as will promote national security and welfare. The greater part of the work of the Council is done by an Executive Committee, which meets fortnightly. Committees have also been established to prepare a national census of research and of the equipment and *personnel* available, and for other purposes of organization.

Research committees of two classes have been appointed—(*a*) central committees, representing various departments of science, comprised of leading authorities in each particular field: (*b*) local committees in universities, colleges, and other co-operating institutions engaged in scientific research.

The preliminary plan of procedure recommended by the National Research Council, and approved by the council of the National Academy, is as follows :—

(*a*) The preparation of a national census of equipment for research, of the men engaged in it, and of the lines of investigation pursued in co-operating Government bureaux, education institutions, research foundations, and industrial research laboratories.

* See also—Industrial Research in the United States of America, by A. P. M. Fleming, M.I.E.E., published for the Department of Scientific and Industrial Research, London, 1917.

(*b*) The preparation of reports by special committees, suggesting important research problems and favourable opportunities for research in various departments of science.

(*c*) The promotion of co-operation in research, with the object of securing increased efficiency; but with careful avoidance of any hampering control or interference with individual freedom and initiative.

(*d*) Co-operation with educational institutions, by supporting their efforts to secure larger funds and more favourable conditions for the pursuit of research and the training of students in the methods and spirit of investigation.

(*e*) Co-operation with research foundations and other agencies desiring to secure a more effective use of funds available for investigation.

(*f*) The encouragement in co-operating laboratories of researches designed to strengthen the national defence, and to render the United States independent of foreign sources of supply liable to be affected by the war.

It is not intended that the National Council should supersede or interfere with existing institutions carrying on research, but, where necessary, to increase their utility by placing additional expenditure at their disposal and in other ways. The relation between the central committees and the local and other special committees may be illustrated by reference to chemical research. There is a central committee of chemistry, which deals in the first instance with all industrial problems connected wholly or mainly with chemistry. This Committee devises the specific problems to be investigated, and assigns them to the local committees at certain institutions or to other special committees consisting of experts in the branch in question. In all cases close connexion is retained between the scientist, manufacturer, and business administrator.

Information regarding methods of financing is not available, but it is understood that the Federal Government provides a large sum by grants and through the several Departments. Some of the money is provided by the National Academy of Sciences and by the institutions that carry out the researches.

VIII.—FRANCE.

The question of national laboratories of scientific research was the subject of a report by a Committee of the Paris Academy of Sciences in November last. The Committee pointed out that all the great industrial nations possess national laboratories of scientific research, systematically directed towards the study of technical problems. The National Physical Laboratory in England, the Bureau of Standards and the Carnegie Institution of the United States, the Physikälische Reichsanstalt, and the Institutes founded by the Wilhelm Gesellschaft in Germany are given as examples. France has no corresponding institution, and after a full discussion of the questions of control, staff, and work to be done, the following resolution was unanimously carried:—"The Academy of Sciences, convinced of the necessity of organizing in France, in a systematic manner, certain scientific researches, expresses its wish that a National Physical Laboratory should be started, for the prosecution of scientific researches useful to the progress of industry. As in other countries, this laboratory would be placed under the control and direction of the Academy of Sciences." It is suggested that the general direction of the laboratory shall be entrusted to a Council, one-half of the members nominated by the academy, one-quarter representatives of the State departments, and the remaining quarter delegated by the principal industrial interests.

IX.—JAPAN.

In Japan steps have been taken for the establishment at Tokio of a National Laboratory for Scientific and Industrial Research. The chief work of the institution will be to develop Japanese industries by the application of modern methods and the results of the researches which are to be carried out. The main sections of the Laboratory will be devoted respectively to the following subjects :—

(*a*) Electricty and Electro-chemistry.
(*b*) Lighting.
(*c*) Scientific apparatus.
(*d*) Drugs, dyes, perfumes, rubber, &c.
(*e*) Artificial or imitation silk.
(*f*) Foodstuffs and beverages.
(*g*) Refrigerating methods.
(*h*) Oils.
(*i*) Fixation of atmospheric nitrogen.
(*j*) Utilisation of fumes from metallurgical works.
(*k*) Prevention of explosions in coal mines.
(*l*) Microscopic research with iron and steel.
(*m*) Steam turbines.
(*n*) Resistance, power, and speed of ships.
(*o*) Arms and ammunition.
(*p*) Fire-proof and earthquake-proof buildings.

To cover the expenses Parliament has voted a sum of over £200,000, payable in instalments over a period of ten years. The Emperor of Japan has granted a sum of over £100,000, while a further sum of about £220,000 has been collected from various institutions and private individuals. The total fund for the Laboratory thus amounts to over £520,000.

The control of the work is in the hands of a General Council consisting of 50 members. There are ten "Managing Directors" and four "Business Managers." The organization is attached to the Government through the Department of Agriculture and Commerce.

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By

GERALD LIGHTFOOT, M.A.

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CONTENTS.

SUMMARY.

1. The main objects of standardisation are to cheapen manufacture, to effect improvement in quality and design, to increase production, to reduce maintenance charges and variety of stocks, and to secure interchangeability of parts. Broadly speaking, the benefits of standardisation are mass production and reduced cost per unit product. Both producers and consumers are therefore vitally concerned in standardisation.

2. In other countries, notably Great Britain and the United States of America, engineering standardisation has reached a high stage of development. In Australia, with few exceptions, the multiplicity of standards is in effect tantamount to an absence of standards. The results are inconvenience, waste of effort, increased cost, delay in executing orders, reduced output, and a general lowering of efficiency.

3. Several factors, including the keen industrial competition arising out of the war, the demands of labour for a higher standard of living, and the importance of stimulating industrial enterprise, make it now more urgent than ever that the engineering industry in Australia should introduce modern order and system into all its methods of production.

4. The British Engineering Standards Association, established in 1901, has developed a far-reaching organisation, consisting of some 170 Sectional Committees, Sub-committees, and Panel Committees, dealing under one central authority with practically the whole field of engineering. It is financed by the British Government, by certain of the self-governing Dominions, by various institutions and bodies, and by the engineering industry itself, and has carried out a large amount of standardising work of the highest importance.

5. Standardising Committees have recently been formed, or are now in process of formation, under the ægis of the British Association, in a number of important countries throughout the world.

6. In Japan the question of engineering standardisation has been actively taken up. Special attention has been directed to the standardisation of ships and ship-building materials.

7. The International Association for Testing Materials was established in 1895, and before the war had a membership of nearly 3,000, representing 31 different countries.

8. The American Society for Testing Materials was founded in 1898, and by 1918 had adopted standard specifications, covering 132 engineering materials. It is strongly supported by the technical departments of the Federal Government, by engineering associations and societies, by corporations, and by manufacturers and users throughout the United States.

9. The method adopted in Germany before the war for standardisation and specialization through " kartels " is well known, and was largely responsible for the remarkable progress in the engineering industry in that country.

10. Engineering standardisation is now being actively taken up throughout the world, and if Australia neglects to take action in this matter, it will be impracticable to maintain and develop her engineering industries, and other industries dependent thereon, at the same level of efficiency as in other countries.

11. The Institute of Science and Industry does not desire to establish standards itself, but merely to provide the organisation and otherwise assist the engineers of Australia to do the work for themselves. It thinks that the matter is of such importance that the Commonwealth Government should lend its moral and financial support to the movement.

12. Scientific research work is essential in the preparation of standard specifications. The Institute desires to assist in carrying out such work on lines similar to those in the case of the United States Bureau of Standards, the British National Physical Laboratory, and other national research institutions.

13. Representative conferences of leading engineers, convened in each State by the Institute towards the end of 1918, unanimously supported the movement for the formation of a Commonwealth Engineering Standards Association. Practically all the engineering associations and societies in Australia were represented at these conferences.

14. The outline of a scheme for the formation of a Commonwealth Engineering Standards Association is furnished. It is suggested that a Main Committee be appointed representative of Engineering Associations and of Commonwealth and State Government Technical Departments. The Commonwealth Government, through the Institute of Science and Industry, would make the necessary arrangements for funds, partly by direct grant and partly by obtaining contributions from other sources, and would formally appoint the members of the Main Committee. The actual standardising work would be carried out by Sectional Committees appointed by the Main Committee, and, where necessary, the Sectional Committees would appoint Sub-committees in various States. A technical secretary would be appointed to take charge of the work under the Main Committee, and the resources of the Institute of Science and Industry would be available to the Standardising Association for the purposes of both research work and general administration.

15. Standardisation cannot be attained by one section of the community endeavouring to impose its opinions on other sections. Effective agreement can be secured only by common consent of all parties interested, who must take full part in the discussions and in the initiating and working out of the actual details of the specifications. Whatever scheme of organisation be adopted, mutual concession and the sinking of sectional interests and individual opinions are necessary as a condition precedent to the success of the movement.

ENGINEERING STANDARDISATION.

By Gerald Lightfoot, M.A.

I.—INTRODUCTION.

1. General.—Perhaps the most notable step in the realisation of engineering standardisation was taken in 1841, when Sir Joseph Whitworth introduced the standard screw-thread. When urging the necessity for standardisation he illustrated his argument by mentioning that candles and candle-sticks were in use in almost every house, and that nothing would be more convenient than for the candles to fit properly into the sockets of the candle-sticks, which they seldom did. The lesson taught by this illustration lies at the root of standardisation, which carries with it possible disadvantage for the few for the distinct advantage of the many.

Standardisation is now generally recognised as being of paramount importance to economic production. Its primary objects are to cheapen manufacture by elimination of waste entailed in producing a multiplicity of qualities and designs for one and the same purpose, to effect improvement in quality, design, and workmanship, to increase production, to reduce maintenance charges and variety of stock, and to secure interchangeability of parts.

2. Benefits to Producers.—From the producers' point of view the two ultimate objects of standardisation are greater output and reduced cost. Obviously a machine continuously producing an article of standardised type or design will have a very much larger output than would be the case if it were necessary to change the tools or dies to meet various specifications. It is obvious that if this principle were applied to the whole of the machinery in a large works, the production would be enormously increased. Moreover, standardisation itself facilitates the adoption of improved processes and types of machinery. For example, only a plant such as Fords could find profitable use for multiple drills which bore dozens of holes into both the top and the sides of several cylinder castings at the same time.

As regards economy in labour, standardisation leads to specialisation in workmanship. In a multiple product factory there may not be enough work of the same kind to keep one man engaged constantly on that work, therefore he is required not only to change his work from time to time, but to be capable of performing several kinds of operations. Apart from the effect in such cases in decreasing the output, greater skill is ordinarily required in a multiple product factory. In a standardised product factory the workmen perform one operation practically continuously and become highly expert at it, so with the aid of automatic machinery a man may operate a number of machines at once. It follows, therefore, that with the same capital cost and plant, and with the same expenditure on wages, a factory can produce many more units of standardised product than its competitor manufacturing multiple products. The cost is still further reduced when the overhead expenses are taken into consideration. The two advantages mentioned are by no means the only advantages resulting from standardisation from the producers' point of view, but all the others lead back to these two, mass production and diminished cost per unit product.

3. Benefits to Consumers.—From the consumers' point of view the main advantages of standardisation are also twofold, viz., reduction in cost and improvement in quality. Reference has already been made to the former. As regards the latter, it has been found in other countries that one of the most important results of standardised specifications is generally to increase the quality of the product. The objection is sometimes taken that standardisation tends towards crystallisation, and thus interferes with progress; but experience has shown that standardisation does not lower the standard, but if anything tends to raise it. Standardisation reflects in effect the consensus of opinion as to what constitutes the best modern practice, with the result that those manufacturers who, prior to the adoption of standards, were producing an inferior article, have to increase the quality or design if they desire to conform to the generally accepted standards. Standards are revised periodically, so as to keep pace with technological progress. This is all to the advantage of the consumers, who obtain a high-grade standard article, and can do so merely by reference to the accepted standard specification. This tends to eliminate disputes, and to simplify the preparation and enforcement of contracts.

The supreme value of standardisation from the point of view of mass production and economy in cost was strongly emphasised during the war. The maintenance of an adequate supply of munitions of war was possible only as the result of standardisation and specialisation, while in regard to civilian clothes and various other materials the exigencies of economical production necessitated the adoption of standardised methods. It is obvious that if in normal times the standardisation of any considerable number of articles and products could be effected, while at the same time making sufficient allowance for individual variations in style and taste, there would be an enormous increase in the efficiency of production, accompanied by a corresponding decrease in cost.

4. Conditions in Australia.—The above remarks apply not only to engineering standardisation, but to the question of standardisation of products in industry generally. Coming now to the particular question of engineering standardisation, it appears that the importance and extent of the progress made in Great Britain, United States of America, and other countries is not adequately and generally appreciated in this country. In Australia, with few exceptions, the multiplicity of standards in some cases, and the absence of standards in others, are a great burden on manufacturers and importers, as well as consumers. One or two examples may be given.

In those countries in which engineering standardisation has been developed, cement is regarded essentially as an engineering material, and standard specifications for this material have been formulated and accepted. In the Commonwealth there are at least eight specifications in use respectively by various Railway departments, Public Works departments, Harbor Trusts, Water and Sewerage Boards, and other bodies. In the opinion of experts there is no reason why a single standard specification should not be adopted in Australia, the specification allowing, where necessary, for certain variations in the tests to which the material must comply according to the use to which it is to be put, *e.g.*, whether for ferro-concrete work, fresh-water, or salt-water. The existing state of affairs causes loss of time, waste of effort and inconvenience to manufacturers, and increased cost to users.

A similar state of affairs exists in regard even to such important materials as railway sections and fish-plates. At the present time there are four specifications for railway rails in use in the Commonwealth, though they differ in minor respects, which cannot be regarded as material, except from the point of view of loss of efficiency in production. For example, one State Railway Department requires that the holes in the rails for the fish-plate bolts shall be $1\frac{1}{4}$-in. diameter, while a neighbouring State requires that they shall be $1\frac{1}{8}$-in. diameter. Moreover, there are differences in the specified lengths of the rails, and there is no uniformity even in the specifications for the composition of the steel used, respectively, for such purposes as dog-spikes on the one hand and fish-plate bolts on the other.

In the electrical engineering industry the multiplicity in the voltages of generating stations in Australia causes great loss, inconvenience, and waste of effort. For example, incandescent lamps are not manufactured in Australia, and in order to supply the needs of the Commonwealth it is necessary for merchants to stock lamps of each candle-power for about twenty different voltages. A similar state of affairs exists in respect to many other electrical fittings and apparatus. It is obvious that this not only causes large additional expenditure in carrying stocks, but it renders it a matter of great difficulty to establish in Australia the manufacture of such fittings and apparatus.

Numerous other similar examples might be given of the multiplicity of engineering standards in Australia and of the resulting inefficiency and cramping effect on industry. In many cases the effect of the multiplicity of standards is the same as if there were no standards at all. It appears that there is not one engineering material for which a single standard specification is in general use in the Commonwealth. The resultant loss to the Commonwealth, and the indirect effect in hampering industrial development cannot, of course, be expressed in pounds, shillings, and pence, but it is clear that it must run into very large sums annually.

Several factors, including the keen commercial and industrial competition arising out of the war, the demands of labour for a higher standard of living, coupled with the policy generally accepted in the Commonwealth for stimulating industrial enterprise, make it now more urgent than ever that the engineering industry in Australia should introduce modern order and system into all its methods of production. If this is to be accomplished existing individualistic methods must give way, where practicable, to co-ordination and collective effort. It is in fact co-operation that will give the highest value to individualistic effort. If through some comprehensive and authoritative central body both producers and users of engineering materials can be induced to accept agreed standards, the community interests of buyer and seller will thereby be realised and a high average efficiency secured.

From the information given in the following pages it will be seen that the organisations for engineering standardisation, notably in Great Britain and the United States of America, have already reached a high state of development and efficiency, and that work of the greatest value and importance has been carried out by them. It is even more important to note that similar organisations have recently been, or are now being, established in many countries, including China, Japan, Chile, India, Portugal, Peru, Spain, South Africa, and Canada.

If, therefore, Australia's engineering industries, and other industries dependent thereon, are to be maintained and developed along the most efficient lines, the establishment of some effective organisation to take up the question of engineering standardisation is of the highest importance.

II.—THE BRITISH ENGINEERING STANDARDS ASSOCIATION.

1. General.—At the beginning of the present century neither the necessity nor the value of engineering standardisation, and still less its intimate relations to economy and speed of production, were at all generally recognised, and it was to remedy this state of affairs that steps were taken in 1901 by the Council of the Institution of Civil Engineers to establish a British Engineering Standards Committee. The Institution first appointed a Committee to consider the standardisation of iron and steel sections. At the first meeting of this Committee it was decided to invite the Institution of Mechanical Engineers, the Institution of Naval Architects, and the Iron and Steel Institute to nominate members on the Committee. Soon after this the work of the Committee was enlarged, and the Institution of Electrical Engineers was invited to nominate two members on the Committee. From this small nucleus a far-reaching organisation has developed with some 170 Sectional Committees, Sub-committees, and Panel Committees, including in all over 900 members, and dealing under one central authority with standards relating to practically the whole field of engineering.

2. Organisation.—(*a*) *The Main Committee.*—The Main Committee, as the governing Committee is called, consists of 24 members, nineteen of whom are nominated by the leading technical institutions, viz., seven by the Institutions of Civil Engineers, and three each by the Institutions of Mechanical Engineers, Naval Architects, Electrical Engineers, and the Iron and Steel Institute. The Main Committee also includes two representatives of the Federation of British Industries, and three members, not representative of any Institution or Association, but elected for their eminence in the engineering profession. These five members are co-opted by the nominated members of the Committee. The members of the Federation of British Industries give the various manufacturing associations connected with the work of standardisation a direct channel through which to place their views before the Main or Executive Committee of the Association. One-third of each group of nominated members retires annually.

The Main Committee controls the whole organisation of the Association, including the raising of the necessary funds, the controlling of the expenditure, the arranging of the subjects to be dealt with by the Sectional Committees, and the passing of all reports prior to publication.

(*b*) *Sectional Committees.*—The procedure before embarking on any new subject is to ascertain by means of a representative conference that there is a volume of opinion favorable to the work being undertaken. If such is the case, the Main Committee nominates the Chairman of a Sectional Committee to take up the work in question, this Committee being formed of technical officers representative of the various Government departments interested, consulting engineers, manufacturers, contractors and users, and representatives of the technical societies and trade organisations concerned. The Main Committee does not dictate in any way either the number of members or the *personnel* of a Sectional Committee, only reserving to itself the right to nominate the Chairman, though naturally it is guided in this matter also by the advice of the members.

The Sectional Committee decides the broad lines upon which the specification is to be drawn up, leaving the detailed work of drafting to a Sub-committee. In many cases the preparatory work in connexion with the draft specifications is intrusted to a Panel, consisting of certain members of the Sub-committee, with co-opted members having special expert knowledge of the subject under consideration. Information is collected by means of lists of questions sent to persons particularly interested, and, if necessary, conferences are arranged from time to time. When the draft specification is prepared, it is submitted to the Sectional Committee for consideration, and when approved is sent on to the Main Committee for final approval and publication.

In September, 1918, the number of Sectional Committees in existence was 21, the number of Sub-committees 73, and of Panel Committees 77. A complete list of them is given in Appendix I. hereof. Members of all Committees, Sub-committees, and Panels become members of the Association, but members, as private individuals, are not asked to subscribe to the funds.

3. Finance.—In regard to the question of finance, the funds for carrying out the work of the Association have been provided by the Governments and the industries concerned. In 1903 the British Government included in the Estimates a contribution of £3,000, which was subsequently increased for the years 1904–5–6 by an annual grant equal to the amount contributed annually by the supporting institutions, manufacturers, and others. This was continued on a smaller scale down to 1916, and a further grant on the same condition was continued to 1919. The Indian Government has been a generous supporter of the Association, and the Governments of other Overseas Dominions, including the Governments of New South Wales, Queensland, South Australia, and Victoria, also contribute to the funds. A liberal response to the Association's appeal for funds has been made by the engineering industry of Great Britain, and also by railway, shipping, and other companies, and by some of the Local Government Boards and the tramway and electricity authorities. The expense of the whole organisation up to the war were under £4,000 a year, but, owing to the widening of the field of its labours, this amount has been very greatly exceeded in recent years.

4. Registered Mark.—The Association's mark or brand, which was introduced in 1903, has come very widely into use, and is now of great importance to the British engineering industry. Mainly with a view to securing undisputed legal right to its mark, to be used by manufacturers as a hall-mark of goods made in accordance with the standard specifications, steps were taken in 1915 for the incorporation of the organisation, so that the mark could be held in the name of the Association. The mark has so far been applied to railway and tramway rails, fish-plates, and salt-glazed ware pipes. Arrangements have recently been made for its more extended use by British manufacturers.

III.—EXTENSION TO OTHER COUNTRIES.

1. General.—Although the activities of the British Engineering Standards Association have in the main been confined to the home country, a considerable amount of work of an international character has been undertaken. Thus the Association is working in close co-operation with the American Institute of Electrical Engineers in several directions in regard to electrical apparatus generally, and a very considerable degree of uniformity has now been attained in the two countries in regard to electrical standards. The Association has also recently brought into operation a scheme for assisting in procuring the wider dissemination of British standards, and is undertaking the translation of its more important reports into various foreign languages.

Under the ægis of the Association rapid progress is being made in the formation of Standards Committees of British engineers and traders in thirteen or fourteen of the important trading centres of the world. In the United States of America and France, Engineering Standards Committees are also being established. The importance and value of the work of engineering standardisation is becoming more and more recognised, and the movement has now attained world-wide dimensions.

2. Japan.—In Japan the question of engineering standardisation has been actively taken up, and special attention has been directed to the standardisation of ships and ship-building materials. The Japanese Government has recently issued a report of a Committee appointed to investigate the latter matter. The Committee has divided both freight and war vessels into a number of standard types, and has also standardised the materials required for their construction, including the boilers. The Committee states that the adoption of standards will facilitate the supply of materials and increase the efficiency of the yards, so that the cost of ship-building will be materially reduced. It has recommended that the adoption of the standard types should be enforced, if necessary, by legislation.

3. British Empire.—(*a*) In Canada a strong and representative Engineering Standardisation Committee has been formed.

(*b*) In India the matter was taken up by the Bombay Chamber of Commerce and referred to the Engineering Congress, held at Bombay in 1918. As a result the Indian Government has decided to establish an Indian Engineering Standards Committee somewhat on the lines of the Railway Board of India.

(*c*) In South Africa an Engineering Standards Committee has been established.

4. Other Countries.—Engineering Standards Committees have either recently been formed or are now in process of formation in the Argentine, Brazil, China, Chile, Peru, Portugal, Spain, and Uruguay.

In the United States of America an Engineering Standards Committee was established in 1918, and has been asked by the British organisation to send a representative delegation to England to discuss the question of more direct co-operation between the two countries.

IV.—THE INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

1. Historical.—The International Association for Testing Materials had its origin in a conference of a small group of workers in experimental engineering, held in Munich in 1882. Meetings on a larger scale were subsequently held in Dresden (1884), Berlin (1886), Munich (1888), Vienna (1893), and Zurich (1895). At the Zurich Congress the International Association for Testing Materials was formally organized, the second Congress was held at Stockholm (1897), the third at Budapest (1901), the fourth at Brussels (1906), the fifth at Copenhagen (1909), and the sixth at New York (1912). The seventh Congress, which was to have been held at Petrograd in 1915 was suspended on account of the war. The total membership of the International Association (representing 31 countries) in July, 1914, was 2,769.

2. Objects.—The objects of the Association, as set forth in its by-laws, are :—" The development and unification of standard methods of testing ; the examination of the technically important properties of materials of construction and other materials of practical value, and also the perfecting of apparatus used for this purpose." The important subject of standard specifications has, however, also been included more recently within the scope of the Association's activity.

3. Administration.—The affairs of the Association are administered by a Council, consisting of the President and one representative from each country having a membership of twenty or more.

4. Methods.—The original plan was to conduct investigations almost exclusively through the agency of international committees. These committees proved unwieldy, however, by reason of their large membership, with the added difficulties arising from geographical separation and differences of language. In pursuance of resolutions at the Budapest Congress (1901) the Council discharged some of the committees, re-assigning the problems in part to individual referees. In the case of questions of direct international concern, the original international committees are continued. At the International Congresses the reports of these committees, as well as individual contributions by members, are presented and discussed.

V.—THE AMERICAN SOCIETY FOR TESTING MATERIALS.

1. Historical.—With a view of bringing the members of like nationality into closer relations among themselves, and in order to simplify the management and render the work of the International Association more effective, it was decided at the Stockholm Congress (1897) to encourage the consolidation of the membership in the various countries into separate national organisations. In pursuance of this action the American members met in Philadelphia in 1898, and established the American section of the International Association for Testing Materials. In 1902 the Executive Committee of the American section applied for a charter under the laws of the State of Pennsylvania for purposes of incorporation under the proposed new name of the " American Society for Testing Materials." This charter was duly granted, and at the fifth annual meeting, held in 1902, it was unanimously adopted.

2. Objects.—The objects of the Society are essentially identical with those of the International Association, with which it stands in direct organic relation, both through its membership in the same as a body, and through the individual membership on the part of many of its members.

As stated in the charter : " The corporation is formed for the promotion of knowledge of the materials of engineering, and the standardisation of specifications and the methods of testing."

3. Membership.—Membership may be held by individuals, firms, corporations, technical or scientific societies, companies, teaching faculties and libraries. There are three classes of members—(*a*) Honorary members, (*b*) members, and (*c*) junior members. A junior member must be less than 30 years of age, and his status is changed to that of member when he attains that age. A junior member is entitled to the full privileges of membership, except that he may not hold office. The total membership of the American Society in 1917 was 2,167. The subscription per annum is £3, or £1 10s. for junior members.

4. Organisation.—The work of the Society is carried out by an Executive Committee, consisting of eighteen members, and by a number of Standing Committees and Sub-committees. The Standing Committees present their reports and recommendations at the annual meetings of the Society. In general, proposed new standards or proposed changes in existing standards are published for one or more years in the Proceedings of the Society as tentative standards before they are formally adopted. The tentative standards are published in the Proceedings with a view of eliciting criticism, of which the Standing Committee concerned takes due cognisance before recommending the formal adoption of the standards. Most of the Standing Committees have appointed a number of Sub-committees, each of which deals with some special branch of the subject. In 1918 there were 38 Standing Committees and 138 Sub-committees in existence. A list of the Standing Committees and their respective Sub-committees is given in Appendix II. of this pamphlet.

On the various Committees the practice has been adopted of maintaining an equal numerical balance between the representatives of producing and non-producing interests, but the latter may predominate numerically with the consent of the former. The creation of new Standing Committees is subject to the authorization of the Executive Committee of the Society, acting on the recommendation of the annual meeting or on its own initiative. The first appointments to Standing Committees are made by the Executive and at a later stage additional members are added on the recommendation of the Standing Committees themselves. When a new Standing Committee is established, the President of the Society appoints a Chairman *pro tem.* selected from the representatives of the non-producing interests. At the first meeting of a Standard Committee a permanent Chairman and other officers are appointed.

In the Report of the Society for the year 1918 the list of standards adopted covers 132 engineering materials. Most of the standards have been revised since their first adoption, some of them as often as six times. The tentative standards numbered 49 in the same year.

5. Finance.—The current expenses of Standing Committees, including stationery, postage, &c., are paid from the funds of the Society ; but expenses for other items are not so paid, unless previously authorized by the Executive Committee of the Society. Committees engaged on subjects having a commercial bearing may solicit contributions from manufacturers towards research funds, but contributions from consumers may be solicited only by the Executive Committee.

The various technical and scientific departments of the Federal Government, such as the Bureau of Chemistry, the Bureau of Mines, the Forest Products Laboratory, the Bureau of Standards, and the Federal Arsenal co-operate closely in the work of the Society.

VI.—PROPOSED COMMONWEALTH ENGINEERING STANDARDS ASSOCIATION.

1. Relation of Institute of Science and Industry to Engineering Standardisation.—From the very beginning of the movement to establish a Commonwealth Institute of Science and Industry it has been intended that the Institute should concern itself actively in the work of standardisation. Thus, in the Report of the original Conference convened by the Prime Minister in January, 1916, when the scheme of work and organisation of the Institute was first outlined, it was stated that—" The highly specialized intricate work of standardising electrical instruments and other scientific apparatus for use as sub-standards by different Government departments, and other institutions in which research work may be carried on, would also naturally fall within the functions of the Institute."

In a Report made by the Executive Committee of the Institute to the Commonwealth Government in July, 1917, the importance of this work was emphasized, and it was recommended that any new National Laboratories which may be created for special purposes of research and experimental inquiry, should include a laboratory for testing and standardising purposes.

The Institute has collected information both from published documents and by personal interview with experts regarding the organisation and work of standardising institutions in other countries, and has considered the probable requirements of Australia in connexion with this class of work. As regards the work of engineering standardisation in Australia, it should be clearly understood that the Institute does not in any way desire to carry out this work itself. It is believed, however, that the organisation is more likely to be successfully established if the movement is initiated by some Commonwealth body, which is entirely free from State or sectional interests. It is thought, moreover, that the movement is of such fundamental importance to the efficient development and organisation of our industries, that it should be accorded the moral and financial support of the Commonwealth Government, which is of course a large consumer of many of the engineering materials for which it is proposed that standard specifications shall be prepared. The Institute, therefore, desires to provide the organisation, and to otherwise assist the engineers of Australia to do the work for themselves through their Associations and Societies.

2. Scientific Research and Engineering Standardisation.—There is, moreover, another consideration of fundamental importance which necessitates that the national Government should actively concern itself in the standardisation movement. Scientific research work upon problems connected with standardisation is a necessity. This work is based upon the modern view that quality depends upon definite measurable or determinable properties, and it therefore requires access to standard measuring apparatus and facilities. Scientific problems are in fact constantly arising in all lines of standardisation work. In many cases satisfactory methods of testing are not available, and researches are necessary to devise new methods. Equally important is the study of the practical and scientific basis for specifications, the desirable qualities in materials, their accurate description in terms of physical and chemical properties, which can be tested or measured by standard methods and analysis, standard methods of sampling, and standardised instruments. The relation of chemical research to engineering standardisation is very important. Scarcely a problem can be taken up concerning the specification of standards or properties of materials that does not involve chemical analysis or the co-operation and advice of chemical experts. Fortunately, in the work of preparing standard specifications for Australia there will already be available the results of the very valuable work already completed in other countries, and it may be that in this country it will be practicable to adopt, possibly with no or little modification, some of the standards devised in other countries. Nevertheless it is probable that in certain classes of engineering materials, such for example as paints and varnishes, scientific research work will be necessary before standards can be laid down suited to Australian climatic and other conditions and to Australian raw materials.

It is now generally recognised that scientific research work in connexion with standardisation can be done effectively only by an independent institution under the national Government. Thus in England there is the National Physical Laboratory, in the United States the Bureau of Standards, and in Canada the Dominion Bureau of Standards at Ottawa.

3. Conferences Convened by Institute in each State.—As the outcome of its deliberations on the matter the Institute decided in 1918 to convene representative conferences of engineers in the capital town of each State, with a view to focussing attention on the subject of engineering standardisation and to eliciting the sympathy and support of persons interested. These conferences were convened by the respective State Committees of the Institute for the purpose of considering the following resolutions :—

(*a*) In view of the importance of standardisation of engineering materials and methods, the desirability that such standardisation should be considered for Australia as a whole.

(*b*) In view of the fact that great progress has been made in Great Britain and the United States of America in such work of standardisation, the desirability of accepting such standards as have already been arrived at, provided they are satisfactory to Australian conditions.

(*c*) In cases when British and American standards are equally applicable to Australia, the desirability of selecting the British standards.

(*d*) The desirability of establishing in Australia a representative authoritative body to take the matter in hand.

At each of the conferences resolutions substantially in the form stated above were unanimously passed strongly supporting the movement. The conferences in Victoria, Queensland, and South Australia also passed resolutions affirming the desirability of the Australian organisation being linked up with the British Engineering Standards Association. A summarized statement of the resolutions passed by each conference is given in Appendix III. hereof.

The following list of the persons present, and the organisations represented at the respective conferences, shows that the proposal to establish a Commonwealth Engineering Standards Association is supported not only by individual leading engineers throughout the Commonwealth, but also by practically the whole of the Engineering Institutes and Societies and of the Commonwealth and State Government departments concerned.

STATE CONFERENCES ON ENGINEERING STANDARDISATION.—PERSONS PRESENT AND ORGANISATIONS REPRESENTED, 1918.

(A) VICTORIA.

PROFESSOR T. R. LYLE, F.R.S. (Chairman), Chairman of the Victorian State Committee of the Institute of Science and Industry.
MR. A. E. AUGHTIE, President, Municipal Engineers Association of Victoria.
ENG. COMMANDER W. R. ARKINS, Navy Department.
MR. W. CALDER, M.I.C.E., Chairman Country Roads Board of Victoria.
MR. A. T. CLARK, Engineer of Roads and Bridges, Public Works Department of Victoria.
MR. H. W. CURCHIN, Chief Executive Officer, Commonwealth Ship Construction.
MR. T. D. DOYLE, A.M.I.M.E., Assistant Engineer, Victorian Railways (Rolling Stock Branch).
DR. F. M. GELLATLY, Director, Institute of Science and Industry.
MR. A. GOUDY, Engineer, Victorian Railways (Ways and Works Branch).
MAJOR A. J. GIBSON, A.M.I.C.E., Commonwealth Arsenal and Defence Department.
MR. F. GOLDING, Chief Electrical Engineer, Postmaster-General's Department.
MR. E. T. LEWIS, Victorian Chamber of Manufactures.
MR. H. R. HARPER, City Electrical Engineer, Melbourne.
PROFESSOR T. H. LABY, M.A., University of Melbourne.
MR. W. LEITCH, C.B.E., Director, Bureau of Commerce and Industry.
MR. A. C. MCKENZIE, A.M.I.C.E., Chief Engineer, Melbourne Harbour Trust.
MR. A. MCKINSTRY, Electrical Association of Australia.
PROFESSOR PAYNE, University, Melbourne.
MR. J. M. REESON, M.I.C.E., Chief Engineer, Metropolitan Gas Company, Melbourne.
MR. E. G. RITCHIE, Metropolitan Board of Works.
MR. J. SARVAAS, M.C.E., Education Department (Technical Schools), Victoria.
MR. H. H. SCHLAPP, Australian Institute of Mining Engineers.
MR. F. STAPLEY, F.R.V.I.A., Vice-President, Victorian Institute of Architects.

(B) NEW SOUTH WALES.

Particulars of persons present are not available. The following were invited to send representatives, and in nearly every case did so :—

DEPARTMENT OF PUBLIC WORKS.
CUSTOMS DEPARTMENT.
DEFENCE DEPARTMENT.
CAPTAIN IN CHARGE, NAVAL ESTABLISHMENTS, GARDEN ISLAND.
GENERAL MANAGER, NAVAL DOCKYARDS, COCKATOO ISLAND.
RAILWAY COMMISSIONERS.
WATER SUPPLY AND SEWERAGE BOARD.
WATER CONSERVATION AND IRRIGATION COMMISSION.
SYDNEY HARBOUR TRUST.
ENGINEERING ASSOCIATION OF NEW SOUTH WALES.
ELECTRICAL ASSOCIATION OF AUSTRALIA (NEW SOUTH WALES BRANCH).
INSTITUTE OF ARCHITECTS OF NEW SOUTH WALES.
SYDNEY UNIVERSITY ENGINEERING SOCIETY.
CHAMBER OF MANUFACTURES.
IRON TRADE EMPLOYERS' ASSOCIATION OF NEW SOUTH WALES.
MOTOR TRADES' ASSOCIATION.
MUNICIPAL ENGINEERS.
BROKEN HILL PROPRIETARY COMPANY.
MESSRS. G. HOSKINS LIMITED, LITHGOW.
STATE COMMITTEE OF THE INSTITUTE OF SCIENCE AND INDUSTRY.

The following individuals were also personally invited :—

PROFESSOR WARREN (Sydney University), Engineering.
PROFESSOR WILKINSON (Sydney University), Architecture.
ACTING PROFESSOR SUTHERLAND (Sydney University), Mechanical Engineering.
ASSISTANT PROFESSOR MADSEN (Sydney University), Electrical Engineering.
MR. H. J. SWAIN, Sydney Technial College

(C) QUEENSLAND.

MR. NORMAN BELL (Chairman)
MR. D. WIENHOLT
PROFESSOR H. C. RICHARDS
} State Committee of Institute of Science and Industry.
MR. GRIER, Public Works Department.
MR. C. F. PEMBERTON, Railways Department.
MR. W. J. DOAK, Institute of Civil Engineers.
MR. PRESTON, Chamber of Commerce.
MR. J. DOWRIE, Ironmasters' Association.
MR. E. MANCHESTER, Water and Sewerage Board.
MR. J. HENDERSON, Chief Inspector of Machinery.
MR. H. W. MAY, B.E., Engineer, Central Technical College.
MR. J. S. JUST, Manager, City Electric Light Company.

(D) SOUTH AUSTRALIA.

MR. J. B. LABATT, Deputy Chairman, South Australian Harbours Board.
MR. J. C. B. MONCRIEFF, Chief Engineer for Railways.
MR. J. G. STEWART, Engineer in Chief, Railways Department.
MR. F. W. H. WHEADON, Adelaide Electric Supply Company Limited.
MR. L. LAYBOURNE-SMITH, Institute of Architects.
MESSRS. J. H. ROBERTSON, WICHKAM, and S. W. DURKIN, Institute of Engineers.
PROFESSOR RENNIE, State Committee of the Institute of Science and Industry.

(E) WESTERN AUSTRALIA.

MR. J. R. W. GARDAM, M.I.E.E., President, West Australian Institution of Engineers.
PROFESSOR PATERSON, State Committee of Institute of Science and Industry.
MR. W. LESLIE, M.I.M.E., Consulting Engineer.
MR. W. J. HANCOCK, M.I.E.E., Government Electrical Engineer.
ACTING PROFESSOR TOMLINSON, University of Western Australia.
MR. C. E. CROCKER, M.I.E.E., General Manager, City of Perth Gas and Electricity Department.
MR. T. M. CAREY, Assoc. M.I.C.E., Electrical Engineer, City of Perth Gas and Electricity Department
MR. E. S. HUME, M.I.M.E., Chief Mechanical Engineer, West Australian Government Railway.
MR. E. A. EVANS, M.I.M.E., Workshops Manager, West Australian Government Railways.
MR. J. PIDGEON, M.I.C.E., Existing Lines Office, West Australian Government Railways.
MR. W. H. SHIELDS, Consulting Engineer.
MR. W. H. TAYLOR, M.I.E.E., Electrical Superintendent, Tramways Department.
MR. J. PARR, A.I.C.E., Engineer, Water Supply Department.
MR. E. H. GLIDDON, City Engineer, Perth City Council.
MESSRS. J. E. LEDGER, R. BENNETT, and T. EILBECK, B.E., Ironmasters' Association.
MR. A. C. BUTCHER, M.I.M.E., Engineer Surveyor, Department of Harbours and Lights.
MR. F. SHAW, Manager, State Engineering Works.
SUB-LIEUTENANT E. MCCANN, Department of the Navy.
MR. J. HAMILTON, Broken Hill Proprietary Limited Steel Company.

(F) TASMANIA.

MESSRS. J. H. BUTTERS (Chairman), SLAYTOR, and VINCENT State Committee of Institute of Science and Industry.
MR. C. B. DAVIES and MR. W. ROSS-REYNOLDS, the Tasmanian Institution of Engineers.
MR. M. KENNEDY, Vice-President of the Chamber of Commerce.
PROFESSOR MACKAY, University of Tasmania.
MR. MEREDITH, Electrolytic Zinc Company.

4. Suggested Commonwealth Organisation.—In considering the question of organisation, it is important in the first place to bear in mind that standardisation cannot be attained by one section of the community endeavouring to impose its opinions on other sections, but only by co-operative action on the part of all concerned. Isolated attempts to secure standardisation of certain materials in Australia in the past have largely failed, for the reason that the organisations established to draft the specifications have not been representative of all the interests concerned. Effective agreement as to standard specifications can only be arrived at by common consent of all the parties interested, who take full part in the discussions and in the initiating and working out of the actual details of the specifications.

While it is hoped that the various engineering institutions and societies in Australia will co-operate in establishing a representative association to carry out the work of standardisation, the Institute of Science and Industry has already, at the request of persons interested, arranged for representative conferences to be held with a view to arriving at an agreement in regard to standard specifications for structural steel sections, railway rails and fish-plates, and tramway rails, respectively. The first of these conferences (Structural Steel Sections) has already been held with entirely successful results. The action taken by the Institute in respect to these matters does not in any way affect the proposal to establish a Commonwealth Engineering Standards Association to take up the whole work, but it was considered undesirable to postpone action in regard to the three matters mentioned until the Association is established. The results already achieved in respect to the standardisation of structural steel sections afford a valuable illustration of the importance and possibilities of the movement.

A skeleton scheme for the organisation of a Commonwealth Engineering Standards Association is outlined in the diagram on page 21.

(i) *The Main Committee.*—It is suggested that, as in England and the United States of America, there should be a Main or Executive Committee, consisting of not more than from fifteen to twenty members, nominated partly by various Engineering Institutes and Societies in the Commonwealth, and partly by the Commonwealth and State departments concerned. As the work of preparing the specifications would be carried out through Sectional Committees, it is probable that, once the organisation was properly launched, it would be necessary for the whole Main Committee to meet only at infrequent intervals, probably not more than once a year.

The Commonwealth Government, through the Institute of Science and Industry, would be responsible for finding the funds for the work, partly by direct grant and partly by obtaining contributions from various sources. The Commonwealth Government would also formally appoint the members of the Main Committee. The resources of the Institute of Science and Industry in the several States would be available to the Association for general administrative purposes, and economy in respect to clerical work and the keeping of accounts, &c., would thus be effected, as it would not be necessary to appoint special officers of the Association for these purposes. Neither the Commonwealth Government nor the Institute of Science and Industry would take any part in the standardising work of the Association, except that the Institute would arrange for any experimental work to be carried out when requested to do so by the Association.

The principal functions of the Main Committee would be as follows :—

(*a*) To decide what standardisation work should be undertaken.

(*b*) To appoint the members of the Sectional Committees to which the work of preparing the specifications would be intrusted.

(*c*) To arrange for the carrying out of research work on the recommendation of the Sectional Committees.

(*d*) To receive and pass the reports and specifications of the Sectional Committees.

(*e*) To control finance (through a Standing Committee).

(*f*) To arrange for publication of the specifications (through a Standing Committee).

(*g*) To keep in touch with Engineering Standards organisations in other countries and with the Institute of Science and Industry (especially in respect to research work).

(*h*) To control the secretarial staff of the Association, which staff would carry on the current work of the Association.

(ii) *The Sectional Committees and Sub-committees.*—The Sectional Committee would, as indicated above, be appointed by the Main Committee, and would be responsible for the preparation of the standard specifications. They would consist of representatives of manufacturers, users and engineering associations, and societies. Having decided on the general lines to be adopted in any particular standard specification, the Standing Committee might find it necessary or convenient to refer the actual detailed work of drafting the specifications to Sub-committees, either in each State or in a number of the States. In other cases the most suitable method of procedure might be to convene an Inter-State Conference of representative persons to draft the standard specification, without referring the question for the consideration of Sub-Committees.

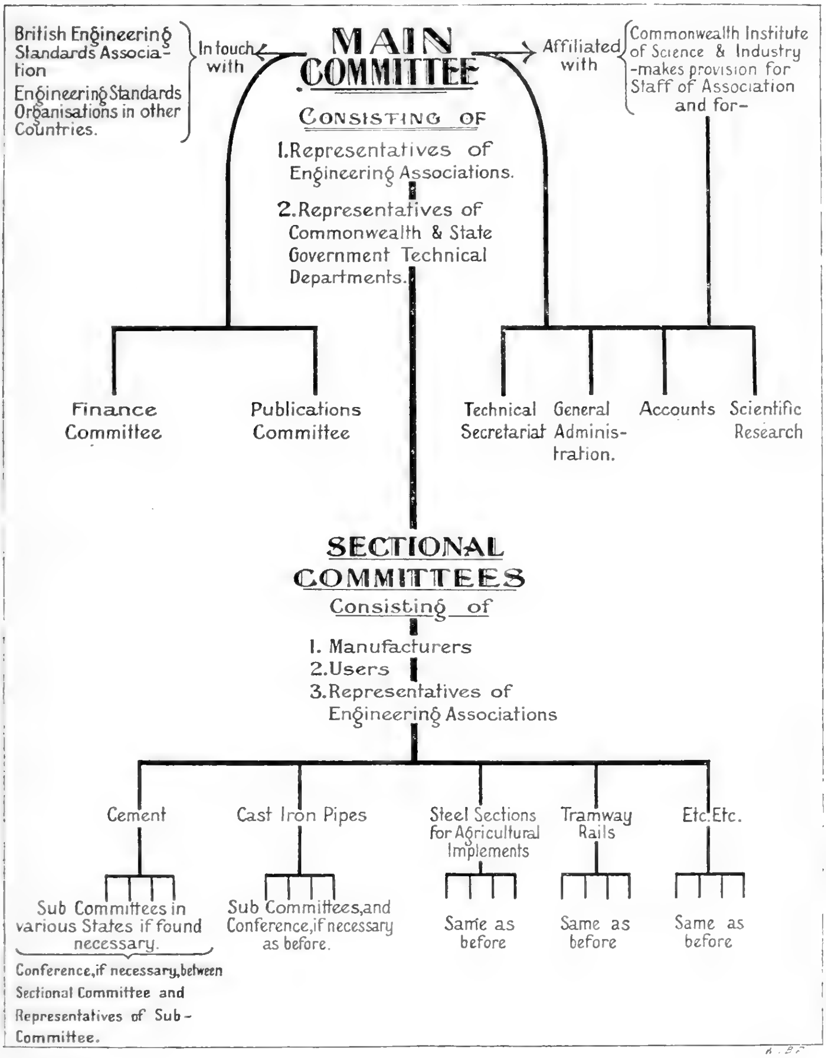
The work of the respective Sub-committees would as far as possible be co-ordinated through the secretarial staff of the Association. The reports of the Sub-committees would be considered by the Sectional Committees, and all outstanding differences cleared up as far as possible by correspondence or by consultation between individual members. If necessary a joint meeting of the Sectional Committee and representatives of the Sub-committees would be held to finally agree upon the specifications.

The Sub-committees would be appointed by the Sectional Committees, and would generally consist of equal numbers of producers and consumers. In carrying out its work in States other than in that State in which the secretariat of the Association is established, the services of the State branches of the Institute of Science and Industry would be at the disposal of the Association.

COMMONWEALTH ENGINEERING STANDARDS ASSOCIATION.

SUGGESTED SCHEME OF ORGANISATION.

Pamphlet No. 2. Engineering Standardisation. *Plate I.*



The scheme of organisation suggested above differs from that adopted either in Great Britain or the United States of America mainly for the reason that it is proposed that the Commonwealth Government, through the Institute of Science and Industry, should assist in establishing and carrying on the work of the Association, and should formally appoint the members of the Main Committee. It is thought that this arrangement is desirable for several reasons. In the first place, it appears probable that by far the greater part of the necessary funds will have to be provided by the Commonwealth Government. Secondly, the Engineering Associations and Societies in Australia are not generally organised on a Federal basis, and the individual associations and societies have not the same National status or scope as that of the institutes which control the standardising movement in England. In view of the conditions obtaining in Australia, it is not likely that the engineering associations and societies will themselves establish a standardising organisation, at any rate, in the near future.

Moreover, the engineering industry in Australia has not yet reached, from the manufacturers' point of view, the same stage of development as in Great Britain or the United States of America, and it would appear to be quite impracticable to establish in Australia an organisation like the American Society for testing materials, which has a large membership behind it, and which is financed mainly by members' subscriptions.

In conclusion, it cannot be too strongly emphasized that, whatever scheme of organisation be adopted, mutual concession and the sinking of sectional interests and individual opinions are necessary as a condition precedent to any effective agreements being reached in the work of standardisation.

The writer is indebted to Mr. S. W. B. McGregor, H.M. Chief Trade Commissioner for Australia, for information concerning the work and organisation of the British Engineering Standards Association. Much valuable information on the subject has been obtained from a paper read by Mr. C. Le Maistre, Secretary of that Association, before the American Society of Mechanical Engineers at its annual meeting at New York in December, 1918.

APPENDIX I.

BRITISH ENGINEERING STANDARDS ASSOCIATION.

LIST OF SECTIONAL COMMITTEES, SUB-COMMITTEES, AND PANEL COMMITTEES, 1918.

Sectional Committees.	Sub-committees.	Panel Committees.
1. Bridges and Building Construction	.. .. ..	1. *Rivet Heads*
2. Sections and Tests for Materials used in Ships and their Machinery	1. Steel Castings and Forgings for Marine Work	
	2. Iron for Ship-building and Ships' Cables	
3. Railway Rolling-stock Underframes		
4. Locomotives ..	1. Locomotive conference	
	2. Component Parts and Types	
	3. Tires, Axles and Springs	1. *Tramway Tires and Axles*
	4. Locomotive Steel Plates	
	5. Copper and its alloys	
	6. Iron for Railway Rolling-stock	
5. Notched Bar Tests		
6. Cement		
7. Electrical (British Section of the International Electrotechnical Commission)	1. Standardisation Rules for Electrical Machinery	1. *Rating* : 2. *Standard pressures*
	2. Physical standards	
	3. Electric Lamps ..	1. *Lamp Holders*
	4. Electric Power Cables	
	5. Electrical Accessories ..	1. *Plugs* : 2. *Switches* : 3. *Terminals and Cable Sockets* : 4. *Watertight Fittings* : 5. *Goliath Screw Lamp Holders*
	6. Telegraphs and Telephones	
	7. Electric Traction	
	8. Prime Movers for Electrical Plant	1. *Steam Turbines* : 2. *Reciprocating Engines* : 3. *Oil and Gas Engines* : 4. *Nomenclature of Prime Movers*
	9. Electrical Nomenclature	
	10. Electrical Symbols ..	1. *Symbols for Electric Lighting and Power Installations* : 2. *Symbols for Telegraphic Work* (*including Wireless Telegraphy*)
	11. Electrical Control Gears	1. *Motor Starters* : 2. *Fuses*
	12. Meters	
	13. Instruments	
	14. Heating and Cooking	
	15. Accumulators	
8. Pipe Flanges ..	1. Pipe Flanges	
9. Rails	.. .. ..	1. *Falling Weight Testing Machine for Rails*
	1. Railway Rails ..	1. *Analyses and Tests for Railway Rails*
	2. Tramway Rails ..	1. *Analyses and Tests for Tramway Rails*
	3. Tire Profiles	

APPENDIX I.—*continued.*

British Engineering Standards Association.—List of Sectional Committees, Etc.—*continued.*

Sectional Committees.	Sub-committees.	Panel Committees.
10. Finance		
11. Publications and Calculations		
12. Cast-iron Pipes ..	1. Hydraulic Power Pipes	
	2. Water, Gas, and Sewage Pipes	
	3. Heating, Ventilating, and House Drainage Pipes	
	4. Electrical Pipes ..	1. *Thickness of Cast-iron Pipes for Water, Gas, and Sewage*
13. Vitrified Ware Pipes ..	.. .. ..	1. *Salt-glazed Ware Pipes*
14. British Standards Abroad		
15. Rope Pulley Groves		
16. Machine Parts, their Gauging and Nomenclature	1. Screw Threads for all Purposes and their Gauging	1. *Screw Thread Experiments:* 2. *Aircraft Screw Threads:* 3. *Modification to form of Screw Threads:* 4. *Munitions Gauges:* 5. *Threads for small Screws:* 6. *Taps*
	2. Limit Gauges for Cylindrical Work	1. *Limit Gauges*
	3. Rolled and Drawn Sections for use in Automatic Machines	
	4. Keys and Keyways	
	5. Metal Tubes and Connexions	
	6. Milling Cutters and Small Tools	1. *Form Relieved Cutters:* 2. *Non-relieved Cutters and Shell-end Mills:* 3. *End Mills:* 4. *Reamers*
17. Wire Ropes		
18. Road Material ..	1. Sizes and Nomenclature of Broken Stone	
	2. Bituminous Materials	1. *Instruments for Testing Tar and Pitch*
	3. Concrete Flags	
19. Galvanized Corrugated Iron and Steel Sheets		
20. Automobile Parts ..	1. Automobile Nomenclature	
	2. Flanges, Tubes, &c.	
	3. Unions, &c.	
	4. Screws, Keys, &c.	
	5. Springs	
	6. Metals	
	7. Frames	
	8. Wheels and Tires	
	9. Controls	
	10. Ball and Roller Bearings	
	11. Tungsten Lamps for Automobiles	
	12. Magnetos	
	13. Sparking Plugs	

APPENDIX I.—*continued.*

BRITISH ENGINEERING STANDARDS ASSOCIATION.—LIST OF SECTIONAL COMMITTEES, ETC.—*continued.*

Sectional Committees.	Sub-committees.	Panel Committees.
21. Components of Aircraft and Aircraft Engines (British Section of the International Aircraft Standards Commission)	1. Nomenclature	
	2. Timber	1. *Timber Specifications and Testings: 2. Seasoning: 3. Conversion: 4. Glue, Cement, and Plywood: 5. Timber Protection*
	3. Propeller Hubs and Fixing	1. *Hubs: 2. Shaft*
	4. Water and Fuel System	1. *Flexible Connexions: 2. Co-ordination of Parts*
	5. Electrical Parts ..	1. *Switches and Plugs: 2. Accumulators: 3. High Tension Switches: 4. Lighting and Heating: 5. Engine Starters: 6. Cables: 7. Navigation Lamps: 8. Distribution*
	6. Instruments	
	7. Ball and Roller Bearings	1. *Ball Bearings*
	8. Sparking Plugs	
	9. Magnetos	
	10. Wheels and Tires	
	11. Structural and Exhaust Pipe Tubing	1. *Revisions*
	12. Rigging and Components	1. *Eyelets and Eyebolts: 2. Cables, Wire, and Taper Sockets: 3. Wires and Rods: 4. Turnbuckles: 5. Pulleys and Fairleads*
	13. Rubber and Miscellaneous Non-metallic Materials	1. *Shock Absorbers: 2. Petrol Resisting Tubing: 3. Rubber Sponge and Armouring: 4. Fluxes for Soldering and Brazing*
	14. Dopes and Fabrics ..	1. *Dope: 2. Cotton Fabric: 3. Linen Fabric: 4. Protective Covering: 5. Ropes*
	15. Aircraft Steels ..	1. *Revisions: 2. Wrought Steels: 3. Sheet Steels: 4. Cold-worked Steels: 5. Valve Steels*
	16. Copper Alloys ..	1. *Brass and Copper Tubes: 2. Brass Rods: 3. Brass and Copper Sheets: 4. Casting Alloys*
	17. Installation of Apparatus	
	18. Lubricating Oil and Petrol	
	19. Cast Iron	
	20. Paints and Varnishes	

APPENDIX II.

AMERICAN SOCIETY FOR TESTING MATERIALS.

LIST OF STANDING COMMITTEES AND SUB-COMMITTEES, 1918.

Standing Committees.	Sub-committees.
	(A)—FERROUS METALS.
1. Steel	1. Steel Rails and Accessories; 2. Structural Steel for Bridges, Buildings, and Rolling Stock; 3. Structural Steel for Ships; 4. Spring Steel and Steel Springs; 5. Steel Reinforcement Bars; 6. Steel Forgings and Billets; 7. Rolled Steel Wheels and Steel Tires; 8. Steel Castings; 9. Steel Tubing and Pipe; 10. Automobile Steels; 11. Boiler Steel; 12. Methods of Chemical Analysis; 13. Methods of Physical Tests; 14. Tool Steel; 15. Cold-drawn Steel; 16. Cast Steel Chain; 17. Literary Form
2. Wrought Iron	1. Tubes and Pipe; 2. Merchant Bar Iron; 3. Staybolt and Engine Bolt Iron; 4. Plates and Shapes; 5. Chain Iron and Iron Chain; 6. Wrought Iron Blooms and Forgings
3. Cast Iron	1. Pig Iron; 2. Pipe; 3. Cylinders; 4. Car Wheels; 5. Cast-iron Scrap; 6. General Castings; 7. Microstructure of Cast Iron; 8. Cast-iron Soil Pipe and Fittings; 9. Molding Sand
4. Heat Treatment of Iron and Steel	
5. Corrosion of Iron and Steel	1. Construction; 2. Preservative Metallic Coatings for Metals; 3. Inspection; 4. The Corrosion of Iron and Steel in Cement and Patent Plaster
6. Magnetic Properties	
7. Malleable Castings	
8. Magnetic Analysis	(In course of organisation)
	(B)—NON-FERROUS METALS.
9. Copper Wire	
10. Non-ferrous Metals and Alloys	1. Pure Metals in Ingot Form; 2. Wrought Metals and Alloys; 3. Sand Cast Metals and Alloys; 4. White Metals, Tin, Lead, and Zinc Base; 5. Plates, Tubes, and Staybolts for Locomotives; 6. Non-ferrous Alloys for Railroad Equipment; 7. Methods of Chemical Analysis; 8. Aluminum Alloys, Cast and Wrought
	(C)—CEMENT, LIME, GYPSUM, AND CLAY PRODUCTS.
11. Cement	1. Definition and Chemical Limitations; 2. Specific Gravity; 3. Fineness; 4. Soundness and Constancy of Volume; 5. Normal Consistency; 6. Time of Setting; 7. Strength; 8. Sampling, Storage, Packages, and Inspection; 9. General Clauses; 10. Natural Cement
12. Reinforced Concrete	
13. Brick	
14. Clay and Cement Sewer Pipe	1. Absorption and Hydrostatic Pressure Test Requirements; 2. Chemical Requirements; 3. Dimensions and their Permissible Variations; 4. Certain Legal Definitions; 5. Glossary of Terms
15. Fireproofing	
16. Drain Tiles	
17. Lime	

APPENDIX II.—*continued.*

American Society for Testing Materials.—List of Standing Committees and Sub-Committees, 1918—*continued.*

Standing Committees.	Sub-committees.
	(C)—Cement, Lime, Gypsum, and Clay Products—*continued.*
18. Refractories	1. Fusion Tests; 2. Analysis; 3. Industrial Survey; 4. Thermal Conductivity and Thermal Expansion; 5. Porosity and Permanent Volume Change; 6. Load Tests at High Temperatures; 7. Spalling Action; 8. Slagging Action
19. Concrete and Concrete Aggregates	1. Definitions; 2. Laboratory Tests for Concrete and Laws of Mechanical Mixtures; 3. Sampling and Testing Field Concrete; 4. Relative Values of various Strength Tests; 5. Impurities affecting fine Aggregates; 6. Methods of Tests for Voids, Weights, Density, Specific Gravity, and Consistency; 7. Methods of Tests of Coarse Aggregates; 8. Available Aggregates for Concrete; 9. Specifications for Fine Aggregates
20. Hollow Building Tiles ..	1. Strength and Load Test; 2. Fire Tests; 3. Absorption and Forest Resistance; 4. Insulation and Acoustics
21. Gypsum	1. Gypsum for Various Uses; 2. Gypsum Plasters; 3. Structural Gypsum Products; 4. Testing Methods; 5. Nomenclature
	(D)—Miscellaneous Materials.
22. Preservative Coatings for Structural Materials	1. Testing of Paint Vehicles; 2. Linseed Oil; 3. Definitions of Terms used in Paint Specifications; 4. Acclerated Tests and the influence of Pigments on Corrosion; 5. Methods of Analysis of Paint Materials; 6. Varnish; 7. Paint thinners other than Turpentine; 8. Turpentine; 9. Shellac; 10. Preparation of Iron and Steel Surfaces for Painting; 11. Specifications for Pigments dry in Oil when marketed in form; 12. Terms used in reporting the Condition of Painted Surfaces; 13. Testing of Pigments for Fineness by the use of Screens; 14. Physical Properties of Paint Materials
23. Lubricants	
24. Methods of Sampling and Analysis of Coal	
25. Road Materials	1. Bituminous Road and Paving Materials; 2. Non-bituminous Road and Paving Materials
26. Coal	
27. Coke	
28. Timber	1. Classification and Designation of Southern Yellow Pines; 2. Uses of Untreated Yellow Pines; 3. Pacific Coast Timbers; 4. Wooden Paving Blocks; 5. Methods of Preservative Treatment of Timber; 6. Timber Preservatives; 7. Inspection of Treated Timber; 8. Fireproofing of Timber
29. Waterproofing	
30. Electrical Insulating Materials	1. Insulating Varnishes; 2. Moulded Insulated Materials; 3. Sheet Insulation; 4. Liquid Insulation; 5. Porclain Insulation
31. Shipping Containers ..	1. Wooden Boxes

APPENDIX II.—*continued.*

American Society for Testing Materials.—List of Standing Committees and Sub-Committees, 1918—*continued.*

Standing Committees.	Sub-committees.
(D)—Miscellaneous Materials—*continued.*	
32. Rubber Products ..	1. Air Hose; 2. Belting; 3. Cold-water Hose; 4. Insulated Wire; 5. Packings, Gaskets, and Pump Valves; 6. Steam Hose; 7. Definitions and Nomenclature; 8. Rubber Insulating Tape
33. Textile Materials ..	1. Humidity; 2. Specimens; 3. Testing Machines; 4. Classification and Identification of Fibres and Fabrics; 5. Nomenclature and Specifications; 6. Imperfections and Tolerances
(E)—Miscellaneous Subjects.	
34. Methods of Testing ..	1. Hardness Tests; 2. Nicked Bar Impact Tests; 3. Methods for determining Modulus of Elasticity Elastic Limit, Proportional Limit, &c.; 4. Determination of Density; 5. Effect of Form and Size of Test Pieces on Results of Tensile Tests; 6. Speed of Testing; 7. Form
35. Electrical Standards	
36. Magnification Scales for Micrographs	
37. Standing Committees	
38. Papers and Publications	

APPENDIX III.

CONFERENCES ON ENGINEERING STANDARDISATION CONVENED IN EACH STATE BY INSTITUTE OF SCIENCE AND INDUSTRY, 1918.

ABSTRACT OF INFORMATION.

1. With a view to focussing attention on the matter of engineering standardisation, and eliciting the support of persons interested throughout the Commonwealth, in November, 1918, the Institute requested each State Committee to invite representative persons in the respective States to hold a meeting to discuss the following points :—

(*a*) In view of the importance of standardisation of engineering materials and methods, the desirability that such standardisation should be considered for Australia as a whole.

(*b*) In view of the fact that great progress has been made in Great Britain and the United States of America in such work of standardisation, the desirability of accepting such standards, as have already been arrived at, provided they are satisfactory to Australian conditions.

(*c*) In cases when British and American standards are equally applicable to Australia, the desirability of selecting the British standards.

(*d*) The desirability of establishing in Australia a representative authoritative body to take the matter in hand.

Meetings in each State were accordingly held.

2. In New South Wales three members of the Institute and 31 engineers representing various engineering organizations and Government departments were present. Five resolutions were unanimously passed; the first four being in the terms of the points referred for discussion, as specified in paragraphs (*a*) to (*d*) above. The fifth resolution was as follows :—

(*e*) That, in view of the action in Great Britain, where the British Engineering Standards Committee was formed in 1901 by representatives from the Institute of Civil Engineers, the Institution of Mechanical Engineers, the Institution of Naval Architects, the Iron and Steel Institute, and the Institution of Electrical Engineers, and in view of the action of the United States of America and other foreign countries where standardisation committees have been appointed by the various engineering institutions in those countries, it is recommended that the Engineering Standards Committee of Australia be appointed by the various Engineering Associations or Societies at present existing in Australia, and shall include engineers appointed by the Government departments and public utilities.

This last resolution had been unanimously adopted at a preliminary meeting of representatives of the New South Wales section of the Electrical Association of Australia, the University Engineering Society, and the Engineering Association of New South Wales. It was pointed out during the discussion that the proper body to take the matter in hand is now in progress of formation, viz., the Institution of Australian Engineers.

3. In Victoria four members of the Institute of Science and Industry, and nineteen representatives of engineering organisations, Government departments, &c., were present at the meeting. Resolutions were passed affirming points (*a*) to (*d*) above, and in addition the following was passed unanimously :—

(*e*) It is desirable that such a movement be linked up as a branch of the British Engineering Standards Association.

4. In Queensland three members of the Advisory Council and nine other representatives were present at the meeting. The points referred to in paragraphs (*a*) to (*d*) were unanimously affirmed. In addition the following resolutions were unanimously passed :—

(*e*) That it is the opinion of this meeting that Queensland should be represented on the Local Committee in Australia, which will be in direct communication with the British Engineering Committee in London.

(*f*) That this meeting considers that each State should be separately represented on such sectional sub-committees as may be formed.

APPENDIX III.—*continued.*

Conferences on Engineering Standardisation, etc.—Abstract of Information—*continued.*

5. At the South Australian Conference, in addition to Professor Rennie, Chairman of the State Committee of the Institute, eight representatives of engineering organisations, &c., were present. Resolutions affirming points (*a*) to (*d*) were passed unanimously. In addition the following resolution was passed, with one dissentient :—

(*e*) It is desirable that such a movement be affiliated with the British Engineering Standards Association.

6. In Western Australia, in addition to members of the Institute, thirteen engineering and technical organizations and departments were represented. The following resolutions were passed :—

(*a*) That this meeting cordially supports the principle of standardisation, and the Commonwealth, being part of the British Empire, the meeting is of the opinion that the British standards should be as far as possible adopted in Australia, in preference to setting up separate standards.

(*b*) That the President and Council of the Western Australian Institute of Engineers, together with Professor Ross, of the University of Western Australia, and Mr. Montgomery, of the Western Australian Committee of the Council of Science and Industry, be appointed a committee to keep in touch with the Advisory Council in Melbourne in matters affecting standardisation in Australia.

7. At the Tasmanian Conference three members of the Institute and five representatives of engineering organizations, &c., were present. The three following resolutions were passed unanimously :—

(*a*) That the meeting heartily indorses the suggestion for the establishment of an Engineering Standardisation Committee of Australia, and urges prompt action in connexion therewith. It further recommends that the Committee should be, in the first instance, formed by appointments on the recommendation of the Engineering Societies of Australia, such appointments to include manufacturers' representatives, and also by appointments representing Government departments and public utilities.

(*b*) That the meeting affirms the principle that British standards should be adopted as far as possible.

(*c*) That the representatives present at this meeting undertake to urge upon the bodies they represent to support the principle of standardisation, and to prepare the ground for the Australian Engineering Committees by adopting British standards forthwith wherever possible.

By Authority: Albert J. Mullett, Government Printer, Melbourne.

COMMONWEALTH OF AUSTRALIA

INSTITUTE OF SCIENCE AND INDUSTRY

The Co-operative Development of Australia's Natural Resources

By
GERALD LIGHTFOOT, M.A.

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SIR GEORGE H. KNIBBS, K.B., C.M.G., Etc.,
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CONTENTS.

PREFACE.

Australia is a vast country of great but undeveloped resources, occupied only by a small population. Both from the stand-point of world-politics and in the interest of the inhabitants themselves, these resources need to be developed to the best of our ability. This can be done effectively only by the co-operation of all in any way concerned, and in such work the Institute of Science and Industry could assist materially, by furnishing the necessary scientific guidance.

In some quarters misconceptions have arisen in the past as to the functions of the Institute and its policy in co-operating in scientific work. Mr. G. Lightfoot, by whom this pamphlet has been compiled, has been connected with the Institute since its inception, formerly as Chief Executive Officer of the Advisory Council of Science and Industry, and, since my appointment as Director, as Chief Technological Assistant and Officer in Charge of the Bureau of Information. He is thus well acquainted with the work which the Institute has carried out, with the plans which have been formulated for its development, and with the policy it is intended to pursue.

The objects of this pamphlet are to indicate the part which the Institute should play in the mobilization and development of Australian resources and to show how that object can best be achieved. This, it is believed, will be by investigations on a co-operative basis between the Commonwealth Institute, the State Technical Departments, Universities, scientific societies, industrial organizations, and other similar interests concerned.

G. H. KNIBBS,
Director.

Commonwealth Institute of Science and Industry,
314 Albert-street,
East Melbourne.
21st May, 1923.

The Co-operative Development of Australia's Natural Resources.

"*I believe that the next years are going to be as critical for Australia's history as the period of the war. They will lay the foundation stones of Australia's future development, and that should be enough to bring us together to carry out our tasks.*"—(The Hon. S. M. Bruce, M.P., Prime Minister of Australia.)

"*The objective*" (*i.e.*, of creating the Institute of Science and Industry) "*was to apply to the pastoral, agricultural, mining, and manufacturing industries the resources of science in such a way as to more effectively develop our great heritage. . . . .*"—(The Right Hon. W. M. Hughes, P.C., M.P.)

"*A plentiful supply of cheap power and cheap fuel is the foundation of a Nation's prosperity; upon that foundation rests also the well-being of its people as a whole, reducing in all directions physical toil and increasing the comfort and ease of every individual and every class of society.*"—(Lieutenant-General Sir John Monash, G.C.M.G., K.C.B., &c., Chairman, Electricity Commission of Victoria.)

I.—AUSTRALIA'S RESOURCES.

One of the direct results of the war has been to vastly increase our national debt, so that our Commonwealth estate of 1,900,000,000 acres is now mortgaged for a total sum of £910,000,000, equivalent to 9s. 6d. per acre, or £163 per head of population. Taxation has reached a height previously unheard of, so that a substantial tribute is now levied on all forms of production. Prices have risen enormously and wages have followed in their train. Fortunately with these new burdens there has also come to many an awakened vision, a quickened sense of responsibility, and a determination to "more effectively develop our great heritage," and in so doing to strengthen the economic ties which bind the Empire together.

With new burdens on our shoulders, the increased mortgage on our estate, the higher taxes on production, how are these aspirations possible of realization? There is one way to do this and one way only, and that is by the creation of new wealth through the development of our natural resources. Our resources are abundantly ample for all legitimate satisfactions of a population many times as numerous as that which the Commonwealth now supports. But our resources cannot be developed by labour alone, or by capital alone, but only by labour and capital together backed by the effective co-operation of our administrators and *guided by the application of scientific methods.*

Increased production does not necessarily mean more work, or harder work for the individual. It does, however, mean more efficient work and a new attitude towards work; the desire to make every stroke tell to the utmost. It means the application of scientific methods to all forms of production and the recognition of the fact that successful industry to-day—whether on the farm or in the factory—demands technical knowledge of a high order, skilful management, and organization in marketing. It means the elimination of wasteful methods, the control and eradication of pests and diseases affecting the agricultural and pastoral industries, the investigation of many scientific problems affecting these industries, the systematic assessment and classification of our resources, the adequate utilization of our forest resources, the use of microscopes and pyrometers, slide rules and graphic charts, and self-recording instruments, and the laboratory control of materials and processes. In a word, it means willing, painstaking, and well-rewarded effort, backed by capital, and *above all guided by science and the spirit of research.*

In any plan for the broad development of the natural resources of the Commonwealth necessarily the first step is the collection of definite and accurate information regarding the resources themselves and its systematic classification in such form that it shall be readily available to those who may be expected to utilize it to advantage.

With full appreciation of the work which has been carried out by many State Government Departments and of the valuable publications which have been issued thereon by these Departments, it may be fairly said that, regarding the matter from a national stand-point, information regarding the natural resources of the Commonwealth is generally difficult to obtain in convenient form.

A vast amount of information of the highest practical value has been accumulated by the State Government Departments and by various scientific bodies, trade organizations, industrial corporations, and individuals. The immediate need is, therefore, not so much for new agencies for obtaining new facts, as for an effective organization to collate, classify, and analyze data already available, and to recast into convenient form the immense mass of valuable information regarding Australian resources already existing in official Government reports, scientific and technical journals, company records, and the special reports of individuals.

For a work of this magnitude to attain its full measure of usefulness, *the cordial support and concurrent effort of the various State Government Departments and of scientific and industrial organizations having at heart the welfare of the nation and the development of its resources is obviously essential.*

If all available information were collected and sifted, it would enable bulletins devoted to particular resources or immediate industrial opportunities to be issued from time to time and special reports to be placed, as occasion arises, before any authorities and individuals in Australia and abroad, who may be expected to base industrial developments thereon. Collaterally with the systematization of existing knowledge, in order to pave the way for the adequate development of Australia's resources, it would be necessary to prosecute, on a co-operative basis, industrial scientific research on lines selected for their promise of yielding results of broad general benefit or of immediate advantage to individual communities or industries. This research work would be a natural complement and correlative to any larger plans in which the Commonwealth and State Governments may agree to co-operate for mobilizing the resources of the Commonwealth.

II.—AGRICULTURAL AND PASTORAL PROBLEMS.

The territory comprised within the Commonwealth is sufficient to allot to each individual of our population about 340 acres. At the present time only 15,000,000 acres, or about 1 out of every 130 acres is under cultivation. That area is considerably less than the area in New South Wales and Queensland alone now covered by the prickly pear pest (about 25,000,000 acres). This gives some idea of the extent to which some of the worst of our pests have spread. The loss caused to our agricultural and pastoral industries by various diseases, pests, and parasites now amounts to many millions of pounds sterling per annum. Nearly all the serious pests have been introduced from other countries. Many of them have now spread over the whole or a great part of Australia, and thus in some cases the work of control and eradication will be costly and will take a number of years ; in some cases the operations may have to be continual.

From plant diseases alone the loss has been estimated at £5,000,000 annually. An attempt to estimate the loss from the sheep fly gives as much as £4,000,000 in a bad year. Prickly pear already covers an area in Australia considerably greater than the total area under all forms of cultivation. New South Wales alone has expended £600,000 during the past fifteen years in an attempt to keep back the cattle tick pest. The loss from fruit diseases and pests is estimated at £1,000,000 annually.

The importance of the above figures lies in the fact that it is well within our power not only to vastly increase the area of cultivated land, but also to greatly supplement the productivity of the areas already occupied for agricultural and pastoral purposes.

Fortunately, Australia already possesses in each State a well-organized and highly efficient Department of Agriculture, and it has also well co-ordinated Agricultural Colleges and Experiment Stations. But these Departments are largely occupied in work of an administrative and routine character, and they are admittedly unable to devote the time, staff, and money necessary for the adequate investigation of the many important problems affecting the agricultural and pastoral industries. Nevertheless a considerable amount of valuable work has been accomplished by them with respect to various diseases and pests and other rural problems, but, by reason of the magnitude and difficulty of the problems, that work has generally been of an uncorrelated, and, in some cases, fragmentary nature. It was for the purpose of remedying so patent a defect and of supplementing and co-ordinating the experimental work of the State Agricultural Departments that the Commonwealth Institute of Science and Industry Act specifically provided for the establishment of a Bureau of Agriculture.

Co-operation between the Institute and the State Agricultural Departments has already proved to be effective in regard to various investigations which the Institute has so far been able to undertake, *e.g.*, (*a*) sheep blowfly pest, (*b*) prickly pear pest, (*c*) cattle tick dips, (*d*) viticultural problems, and (*e*) seed improvement; and it is considered that the time has now come when there should be a wide extension and development of these co-operative investigations.

The Commonwealth activities would not interfere in any way with the work of the State Agricultural or other Departments now in progress, but by the pooling of knowledge and resources through the agency of the Commonwealth Institute of Science and Industry, research work on matters indicated hereafter could be carried out more effectively and with greater prospect of success than under any conditions of isolated effort.

It would not be inappropriate if such bodies as the Pastoralists Association, the Graziers Association, the Fruit-growers Association, the Farmers and Settlers Association, and other organizations of primary producers not only actively co-operated in this work, but also contributed to its cost. On the one hand the members of these organizations are closely affected by the problems, and would be the first to benefit by their solution; on the other hand, they could in many instances assist materially in the investigations, not merely financially but also in the collection of information and in the provision of facilities for field experimental work.

Let us glance for a moment at some of the more direct work that claims the attention of those interested in the development of the agricultural and pastoral industries.

Agricultural and Pastoral Industries.—Scope of Investigations Urgently Needed.

A.—Pastoral Industry.

1. *Stock Diseases.*, *e.g.*, (*a*) braxy disease of sheep; (*b*) contagious abortion of cattle, (*c*) contagious pleuro-pneumonia, (*d*) swine fever, (*e*) tuberculosis, (*f*) actinomycosis of cattle, (*g*) poultry diseases, (*h*) bee diseases, (*i*) Kimberley horse disease, (*j*) Midland cattle disease.

2. *Stock Pests* (parasitological).—Life histories of internal and external parasites affecting stock:—

   (i) Life histories not previously investigated.

   (ii) Life histories already studied, but likely to show variation under Australian conditions. Examples—(*a*) Sheep louse fly, (*b*) cattle tick (*c*) warble fly, (*d*) worm nodule, (*e*) blowfly.

3. *Stock Disease Control.*—The most effective and economical methods for the control and final eradication of animal diseases and animal parasites.

4. *Pest Eradication.*—The most economical methods for the suppression of animal pests, such as (*a*) rabbits, (*b*) dingoes, (*c*) flying foxes, (*d*) rats, (*e*) white ants, &c.

5. *Animal Husbandry.*—Silage and fodder conservation, stock feeding, and stock breeding problems.

B.—Agricultural Industry.

1. *Plant Diseases.*—Diseases affecting plants of commercial importance, *e.g.*, (*a*) bunchy top of bananas, (*b*) tomato wilt, (*c*) thready-eye of potato, (*d*) rust and smut of cereals, (*e*) brown spot in mandarins and other citrus diseases, &c.

2. *Plant Pests.*—Life histories and best methods of control and eradication of plant pests, *e.g.*, (*a*) fruit fly, (*b*) cutworm, (*c*) maize grub, &c.

3. *Plant Introduction and Plant Breeding*—Introduction of—

(1) Plants allowing of the development of land at present of no value, *e.g.*, (*a*) sand binders, (*b*) arid district forage plants, &c.

(2) Plants suitable for extensive cultivation in Australia which would open up new industries, *e.g.*, (*a*) fibre plants, (*b*) plants yielding essential oils, dyes, &c.

(3) New varieties of cereals, fruits, vegetables, &c., with special powers of resisting diseases, droughts, &c.

4. *Native Plants.*—The economic possibilities of the native flora of Australia, particular attention being paid to the use of native plants as forage crops and fibre yielders.

5. *Fodder, Forage, and Pasture.*—(1) The improvement of pasture lands in drought areas, (2) restocking depleted native pastures, (3) the carrying capacity of pasture lands.

6. *Obnoxious Weeds and Poison Plants.*—The best methods of eradicating weed pests, *e.g.*, prickly pear, St. John's wort, African box thorn, Cape weed, onion weed.

7. *Irrigation Problems.*—Cultivation of irrigation crops, quantities and periods of application of water, viticultural and citrus fruit problems, canning problems, &c.

8. *The Registration and Standardization* of varieties of (*a*) fruits, (*b*) cereals, (*c*) root crops, (*d*) vegetables, (*e*) fodder crops.

III.—FOREST PRODUCTS.

Despite a long period of waste and destruction—with the end of the reserves of some species of trees not only in sight, but almost within reach—timber still constitutes one of our most important natural resources. Even with adequate measures for re-afforestation it takes many years to produce a crop of wood, and wood-waste, which now constitutes from one-half to two-thirds of the entire tree is potentially too valuable a raw material to be regarded simply as waste. It would therefore seem that the time has come when we should recognise our responsibility to carry out research work on the economical utilization of our timbers, and our forest and mill waste. This has long been recognised in other countries, where properly equipped and staffed Forest Products Laboratories have been established on a national basis, *e.g.*, the U.S.A. Forest Products Laboratory, at Madison (originally costing £50,000 and with an annual expenditure of £42,000 as far back as 1916), and the Canadian Forest Products Laboratory at Montreal.

Certain definite chemical researches on scientific lines have been carried out in various States, especially at the Technological Museum, Sydney, and much important information has been obtained. The work, nevertheless, must still be regarded as only in its infancy, and there can be no question that further researches are urgently required.

The service which the Institute of Science and Industry could render would not overlap or duplicate the efforts of the State Forestry Departments. Experience has shown (*e.g.*, in the case of the paper pulp investigations) that research work on problems of this nature can be undertaken most effectively by a Federal organization working in co-operation with the State Forestry Departments. By pooling their resources the Commonwealth and States would be able to carry out the investigations much more effectively and economically than is possible if each State proceeded independently.

The general nature of experimental work in regard to forest products which should be undertaken is shown hereunder. This work could be carried out most effectively by the Institute in co-operation not only with the State Forestry Departments, but also with the Saw-millers Associations, the Carriage, Waggon, and Motor-body Builders Associations, and other organizations of persons in the timber-using industries :—

(1) Preservation of wood against dry rot, &c.
(2) Preservation of wood to afford protection against white ants, borers, &c.
(3) Properties and uses of woods, including use of woods for various industrial purposes, *e.g.*, aeroplane manufacture, coach and waggon building, tool handles, &c.
(4) Mechanical tests of timbers and standardization of results.
(5) Seasoning of wood, including standardization of conditions for seasoning of different timbers to be used for various industrial purposes, *e.g.*, air-drying and kiln-drying.
(6) Chemical and mechanical utilization of waste wood.
(7) Paper pulp, especially mechanical pulp for newsprint.
(8) Tanning agents.
(9) Essential oils.
(10) Gums and resins.
(11) Drugs and dyes.

The investigations already carried out by the Institute on paper pulp and tanning materials afford excellent examples of the way in which co-operative research may be conducted efficiently in Australia. As regards the paper pulp investigations, the Institute, with the co-operation of the State Forestry Departments, has shown not only that the poor results previously obtained by individual investigators were largely misleading, but that it is practicable to manufacture high-grade chemical pulp and paper from Australian timbers. It appears, moreover, that the economic factors are such as would enable the chemical pulp industry to be established profitably in the Commonwealth. In view of the valuable results already obtained it is clear that the investigations should be extended to include the possibilities of manufacturing mechanical pulp and "newsprint" in Australia.

Results of considerable prospective industrial value have also been obtained from the tanning investigations carried on in co-operation with the State Forestry Department. The results show that the barks of certain trees formerly regarded as waste materials can be utilized commercially as tanning agents.

IV.—MINING AND METALLURGY.

The immediate need for research into Australian problems connected with the mining and treatment of common metals such as lead, zinc, copper, &c., does not appear to be so great as in the case of other primary industries. This is mainly due to the fact that a large proportion of the Australian production of these metals is in the hands of comparatively large and well organized companies who are able to maintain their own research laboratories and staffs of qualified chemists and metallurgists.

A totally different state of affairs exists, however, not only in the case of the less common metals, but also in the case of a large number of common economic minerals such as ochre, barytes, magnesite, mica, asbestos, &c. Comprehensive information regarding deposits of these minerals, their methods of treatment, &c., is not readily available in convenient form. Details of particular deposits are available in the publications of the various State Geological Survey Departments, but these publications in general contain little information concerning the chemistry of manufacture of the various minerals, the purposes for which they are used, and the markets available. Such information is, however, already to a large extent in the possession of chemists and technologists in the several States. Again, accurate information regarding markets and their potential needs for all products capable of manufacture from the minerals under discussion is available in other quarters. Further, the important information concerning the state of knowledge in other countries of a particular mineral is only obtainable by a wide and intensive expert examination of periodical literature, scientific journals, &c.

For the establishment on a stable basis of such industries, it is important that a central body should co-operate with the various State authorities.

industrial organizations, and experts, chiefly as a collector of information concerning deposits and their extent, composition, &c., but also to co-ordinate research and, where necessary, to carry out further investigation. By application to such a body an investor would be able to quickly obtain all pertinent information.

It is desirable, therefore, that bulletins should be issued from time to time, each confined to one particular mineral and containing information regarding all known Australian deposits of that mineral, its principal uses, methods of treatment, economic factors, markets, &c. Some work is already being done in Australia along these suggested lines. For example, the Queensland Government Geologist has published valuable articles on certain minerals; the South Australian Department of Chemistry has carried out researches and published bulletins concerning some South Australian minerals; and the Western Australian Geological Survey has issued valuable publications concerning the economics of minerals occurring in that State. From time to time other State Geological Surveys publish monographs on various minerals of particular interest to their own State. These State activities could form a basis from which the development of our resources could be studied from a national stand-point. By co-operation between the Institute and the State authorities and other bodies such as the Australian Institute of Mining and Metallurgy comprehensive information for Australia as a whole could thus be made available in convenient form.

V.—MANUFACTURING INDUSTRIES.

In other countries large institutions have been established to carry on scientific investigations for the development of their industries, and this movement has been accelerated since the war. For example, in the United States of America the Bureau of Standards was established at a cost of over £300,000, and has an annual expenditure of about £460,000. The Mellon Institute, at Pittsburgh, which engages in research in co-operation with manufacturing industries, cost £100,000 to build and equip, and has an annual expenditure of £77,000. In Great Britain the Department of Scientific and Industrial Research, created about five years ago, has a fund of £1,000,000 for grants to industrial research associations and an annual vote of £200,000. Its total expenditure in 1920–1921 was £550,000. The British National Physical Laboratory expended about £213,000 in 1921–1922. A Fuel Research Station, at a capital cost of no less than £140,000, has been established near London, to investigate such subjects as powdered fuel, domestic heating, power alcohol, the low temperature distillation of coal, and generally the economic utilization of fuel resources. In Japan a National Laboratory for Scientific and Industrial Research has recently been established at Tokio, towards the cost of which the Government provided £200,000 and the Emperor £100,000. These examples could be supplemented largely, but *sufficient has been stated to show the scale on which the modern world is endeavouring to promote the application of science to industry on a co-operative basis.*

In other countries the industries themselves participate in research work on a co-operative basis, and contribute towards its cost. For example, in Great Britain no less than 24 Industrial Research Associations have been established, many of them with large funds and adequate facilities in the way of staff, laboratories, and apparatus. Again, at the Mellon Institute, Pittsburgh, to which reference has already been made, industrial organizations have established no less than 78 Industrial Fellowships for which sums aggregating £200,000 were provided.

Australia could hardly develop immediately its scientific research work on the scale of countries having many times its population and wealth. It is obvious, however, that if this country is to develop her manufacturing industries intelligently and efficiently and is to take her place among the nations of the world she must at least follow the lead of other countries. Those engaged in manufacturing industries should co-operate in formulating and carrying into effect measures for the investigation and solution of scientific and technical problems affecting their industries and should contribute towards the cost of that work.

Since modern industrial development depends fundamentally upon progress in scientific research, no limits can be set to the directions in which such research is likely to be of benefit to the manufacturing industries of the Commonwealth. The following, however, indicates the nature of the investigations which should be undertaken :—

1. *Tanning and Fellmongering.*—Improved processes, utilization of Australian raw materials and development of standard methods.
2. *Pottery.*—Manufacture of white earthenware and pottery, utilization of clay resources. Manufacture of tiles, glazes, enamelled ironware, &c.
3. *Paints, Enamels, and Varnishes.*—Improvement of processes and standardization of products.
4. *Standardization in Industry.*—Preparation of standard specifications with a view to cheapening manufacture, effecting improvement in quality and design, increasing production, reducing maintenance charges and variety of stocks, and securing interchangeability of parts.
5. *Cold Storage and Food Problems.*—Cold storage of meat, fruits, and other perishable products ; investigations as to diseases and organisms affecting such products, and as to most suitable conditions of storage for export.
6. *General Investigations.*—New processes and methods for the utilization of Australian raw materials, the application of known processes and methods to such materials, improvement in existing processes and methods, the investigation of manufacturers' problems, the elimination of waste, and the co-ordination of industries.

VI.—POWER RESOURCES.

Cheap power is essential to the development of practically all other natural resources, and is now recognised to be on a par with labour and materials in so far as it effects economical production. The value of the application of electricity to practically all classes of machinery and processes has been increasingly demonstrated during recent years. The extent to which it may be further applied to cheaper and better mechanical production, to improved transportation services, to electro-chemical and metallurgical processes, to agriculture, and to domestic labour-saving apparatus is incalculable. Cheap power is indeed essential to the industrial and social development of the country and to its political security.

Energy is required to enable mineral ores to be won and refined, for the adequate fertilization of the land, for the harvesting and transportation of its crops and products, and for any comprehensive scheme for the extensive development of Australia's resources as a whole.

Developments in engineering and chemical science in the past decade, and more particularly in electro-chemical, electro-physical, and electro-metallurgical processes, and in the possibility of high-voltage electric transmission, have rendered the importance of cheap power supply even more exigent. Transmission lines exceeding 200 miles in length are in existence to-day, and only financial considerations now set a limit to their possible length. Any distance is feasible, electrically and mechanically. Electro-metallurgy and electro-chemistry have rendered it possible to handle materials not workable by any other means, have made available new materials, and have greatly cheapened the production of many important materials of wide use. Aluminium, calcium-carbide, chromium, cyanide, silicon, carborundum are products rendered commercially possible only by electrical processes, while ammonia from the air, cyanide, alkalies, hypochlorite, phosphorus, calcium, magnesium, and sodium nitrate are produced most economically by such processes. Great developments have recently taken place in the production of electrolytic copper and zinc, in processes for the electric smelting and refining of metallic ores and in the production of alloys, and during the last decade in the utilization of atmospheric nitrogen for the production of nitric acid and the manufacture of nitrates, &c. Important developments in the electrification of both main and suburban railway lines have also occurred recently. All these demand relatively large amounts of energy.

The adequate development of schemes for the supply of cheap power tends to reduce the cost of living, to facilitate the payment of high wages, to improve working and living conditions, to decentralize population from the large towns, to encourage rural development, to maintain a much larger population on the soil, to mitigate industrial troubles, and to add generally to the prosperity and happiness of a Commonwealth.

These considerations indicate that the conservation and utilization of the power resources of Australia are likely to be one of the most important problems in our national development. The solution of the problems undoubtedly involves many complex questions of engineering, administration, and economic investigation.

National systems have been developed for the transportation of passengers, goods, and live stock ; for the transmission of letters by post and of messages and news by telephone, telegraph, cable, and wireless. What is now needed is the development of a comprehensive system for the transmission of energy so as to nationalize the utilization of cheap power and make it available not merely to those in favoured and restricted industrial areas, but also in rural districts.

In view of the high cost of labour and standard of living, the extensive use of power for farming and other operations in country districts is a matter of great importance, to the Commonwealth especially. The introduction of labour-saving devices, wherever possible, is of obvious importance in rendering rural conditions more satisfying, more profitable, more comfortable and attractive, and thus raising the status of the agricultural labourer.

VII.—WATER POWER.

No comprehensive records exist which set forth the amounts, locations, and characteristics of the water powers of the Commonwealth. In Tasmania the Hydro-Electric Department has carried out a large amount of developmental work, and further investigations are in hand. In New South Wales investigations have been made by the Public Works Department and the Irrigation and Water Conservation Commission. In Victoria the Electricity Commissioners and the State Rivers and Water Supply Commission have carried out a large amount of work. Nevertheless in Australia the proportion of total motive power developed from water power is very small. It is striking to find on the Continent of Europe 27 per cent. of the total motive power is derived from water power, in the United States 24 per cent., whilst Australia uses in her manufacturing industries only about 2 per cent.

In the report of the British Committee on "Water Power in the British Empire," it is pointed out that there have been many good reasons for comparative neglect in the past of the development of water power in the Empire. The general abundance of coal in proximity to centres of industry ; the heavy initial outlay necessary to develop large hydro-electric schemes ; the lack of co-ordination between possible producers, users, and financiers of power ; the lack of markets for the energy which would be made available ; and the remoteness of many of the sources of power from present centres of activity have all contributed. Moreover, the highly efficient combination of the hydraulic turbine and the electric generator capable of handling large powers is of comparatively recent development. In order that any hydro-electric scheme comprising extensive hydraulic works and transmission lines shall be economically sound the demand for, and supply of, power must be approximately continuous and uniform. Otherwise a hydro-electric scheme cannot compete financially, excepting under very special conditions, with power generated from fuel near the place of consumption.

Whilst there is no doubt that, owing to wide fluctuations between summer and winter flow of Australian rivers and to the incidence of drought years, the development of hydro-electric schemes in Australia may present difficulties not ordinarily experienced in other countries, yet the systematic investigations that have beeen carried out in New South Wales, Victoria, and Tasmania are now showing valuable results, disproving the oft-repeated assertion that Australia is without water power. The Chief Electrical Engineer of New South Wales, in his last Annual Report, pointed out that water power undoubtedly exists, which can be made available at reasonable capital cost, but that the question of economic development depends upon the population to be served and the industries that may be carried on or the other uses to which it may be applied. The whole question of economical power supply is thus obviously associated closely with other problems, such as land settlement, immigration, industrial development, and decentralization.

As already stated, the questions of hydro-electric development and the supply of cheap power are of supreme importance to the development of our natural resources, yet it is impracticable at present to obtain comprehensive and authoritative information on this matter in convenient form. Co-operation between the Commonwealth Institute of Science and Industry and the State authorities concerned could remedy this. If these authorities would furnish the Institute with all available information regarding the water power resources of their respective States, the latter could undertake the compilation and publication of a Bulletin, presenting the information, for the use of persons concerned, in suitable form. Collaterally with this work, an effort could be made on a co-operative basis by the Institute and the State Departments to furnish further information regarding natural resources which might be developed concurrently with the development of water-power resources.

VIII.—FUEL.

Under our present system at least 95 per cent. of our industrial requirements for power are derived from coal. Coal, however, if properly utilized, should be much more than a source of heat and power. It is a storehouse of chemical products—ammonia, benzol, tar, and about 1,200 important coal-tar dyes and products—and it lends itself readily to transformation into coke and gas. We may therefore ask in what relation does this fundamental resource stand to the co-operative development of the Commonwealth ?

Without expressing any opinion on the merits of the case, it is obvious that our bituminous coal is mined under conditions of industrial unrest which have at times proved disastrous to the community. Its cost to the consumer is generally too high to furnish him with the cheap power necessary for industrial development on a large scale. Old-fashioned coke ovens and hundreds of relatively small and isolated power plants now waste valuable chemicals to an annual total of hundreds of thousands of pounds sterling. The erection of central power plants and the widespread use of either gas or electricity for power purposes would double the effective energy of the coal and would permit besides by-product recovery the saving of large sums now needlessly expended in the transportation of coal.

In other countries plans either have been developed or are now under consideration for the establishment of super-power plants at centres favorably placed for the receipt of coal, the distribution of gas, and the transmission of electrical energy. On a restricted scale there is a similar tendency in Australia. For example, in Brisbane seven municipalities have combined to form a Metropolitan Electricity Board, purchasing electricity in bulk. In Sydney the City Council has completed an arrangement whereby it will purchase power in bulk from the Railways and Tramways Department. In Melbourne the Morwell brown-coal scheme is being developed, and in South Australia the Adelaide Electric Supply Co. is erecting a new power station at Osborne, on the Port River, with an ultimate capacity of 60,000 kw., from which energy will be transmitted to many country towns, including irrigation settlements on the Murray. In Western Australia a scheme has been discussed for the electricity supply of Perth from a large central station situated on the Collie coal-field.

Even in such large super-plants, however, the coal is wastefully used, since the maximum thermal efficiency of the steam generators alone does not exceed about 80 per cent., while the efficiency of the prime movers is such that the power output rarely exceeds 19 per cent. of that theoretically possible. In addition, the valuable content of oils, &c., is burnt, and thus to a large extent wasted. It is in this latter connexion that the concentration of heat-power plant is so valuable. The day is quickly approaching when the natural oil wells of the world will no longer be able to supply the demands made on them for fuel oil, motor spirit, &c. Recognising this fact, other countries are carrying out intensive research on the methods of oil distillation from coal, but while accumulated knowledge during the past few years has brought a solution near, a full technical and economic solution has not yet been reached. It has, however, become fairly evident that the best chances of economical success lie in distillation of oils from coal by carbonizing the latter in a large scale plant, and by utilizing the carbonized residue for the generation of power. Thus, if in the future it becomes technically and economically possible to refine coal, by carbonization or otherwise, into oil products, gas, and solid fuel, the existence of central power stations would facilitate such refinement.

Such a refining process is of particular importance to Australia, as, in addition to the advantages other countries would enjoy, Australia would also be largely helped towards the very desirable position of making herself independent of the outside world for her vital supplies of motor spirit, fuel oil, &c.

Australia annually imports about 35,000,000 gallons of motor spirit. Experimental work in connexion with the low temperature distillation of coal has given indications that ultimately it will be possible to extract up to

10 gallons of motor spirit per ton of coal carbonized. Thus it would only require the carbonization of 3½ million tons of coal to satisfy Australian motor fuel requirements. The coal output from the Northern District of New South Wales in 1921 was 7½ million tons, and of this total 4½ million tons came from the Greta seams. It is thus evident that Australia has a yearly output of coal potentially sufficient to render her independent of outside liquid fuel supplies. In the case of the interruption of sea transport by war or for any other reason it is extremely important that Australia be in such a position of independence.

Other sources of oil fuel are lignites, brown coal, and oil shale. As regards oil shales, success has been reached with certain deposits in other countries, *e.g.*, in Scotland ; but the nature of oil shale differs from place to place, and in order to achieve success with any particular deposit it is necessary to experiment on a small scale, guided of course by the experience of other lands. Similarly with regard to brown coal, a process successful with one deposit is not necessarily successful when applied to material coming from another locality. Here again research intelligently guided by past work is very necessary.

The whole question of power supply and the economic utilization of solid, liquid, and gaseous fuel involves so many interdependent factors that the most effective method of solving the different problems is for one body, in co-operation with the other interests and authorities concerned, to consider them in a broad way. Such a body exists in Great Britain and is known as the Fuel Research Board. If Australia is not to continue to see her fuel supply developed in a precarious, haphazard, and uneconomical manner, it is urgently necessary for her to establish a similar organization. One of the first and foremost functions of this body would be to make itself thoroughly conversant with developments in other countries. At present many individuals in Australia no doubt are acquiring such information along specialized lines, but practically no co-ordination exists and no organization is available whereby their services can be used in the way of a systematic progressive advance towards the most economical treatment of our available fuel supplies.

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PAMPHLET No. 4.

COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

The Bionomics

OF

Smynthurus viridis Linn.

OR THE

South Australian Lucerne Flea

By

F. G. HOLDAWAY, M.Sc.

MELBOURNE, 1927

By Authority:
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Council for Scientific and Industrial Research

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FIGURES.

Bionomics of *Smynthurus viridis*, Linn., the South Australian Lucerne Flea.

By F. G. HOLDAWAY,[1] M.Sc.

1. General.

The present paper is the outcome of observations on a Collembolous insect, known locally as the Lucerne Flea, on account of the depredations it causes on lucerne (alfalfa). The Collembola are not usually considered of great economic importance, though there are occasional references to their occurrence on vegetables and garden plants, e.g., *Smynthurus hortensis*, which has occurred sporadically in great numbers in England (Davies 3) and North America.

At the beginning of the present investigation, practically nothing was known of the life of the "flea" beyond the fact that it appeared in numbers soon after the first autumn rains, and seemed to disappear, or at least decrease considerably, in the early summer.

It has been present in South Australia for over 40 years. Summers (15) stated that it appeared in large numbers in 1884 at Morphettville, near Adelaide, and for several years its presence was viewed with alarm. Froggatt (4) mentioned that a species allied to the European *Smynthurus viridis* appeared in countless millions in lucerne paddocks in South Australia in 1896. There are also a few other references by Spafford and Lea in the *Journal of the Department of Agriculture of South Australia*. In the opinion of Professor Richardson, of the Waite Institute, it is the most important insect pest of field crops in South Australia to-day.

There has been considerable doubt as to the identification of the insect. Froggatt (4) was of the opinion that it was probably indigenous. Lea (7) sent specimens to Silvestri in Italy, who identified them as *Smynthurus viridis*, Linn. Mjoberg collected specimens at Adelaide, and Schott (14), who reported on the Collembola obtained, considered them as belonging to a new variety which he named *S. viridis* var. *medicaginis*.

I found that the insect exhibited considerable variation in colour, and that in the early summer, light yellowish green forms predominated and the dark forms were practically non-existent. From Schott's description it appears that the specimens which he had for examination were light coloured forms. It was ascertained from Dr. R. Pulleine, who was with Dr. Mjoberg when the insects were collected, that they had been taken in September. We now know that in September and October light forms predominate. Hence Schott's specimens were merely seasonal colour variations.

In 1926, I forwarded both dark and light forms to the Director of the Imperial Bureau of Entomology, who submitted them to two autnorities on Collembola, both reporting that they were structurally indistinguishable from *S. viridis*, a common European species. This

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was originally named *Podura viridis*, by Linnaeus (8), but in 1802, Latreille (6) split up *Podura* and erected the genus *Smynthurus* (often misspelt *Sminthurus*) for the two species, *fuscus* and *viridis*.

The Egg.—The egg when laid is semi-fluid, assuming a spherical shape and becoming firm on exposure to the air. It is then pale yellow, smooth, and shiny. Contact with the soil produces a reticulate appearance. The diameter is 0.27 mm.

Oviposition.—Very little seems to be known of the egg laying habits of Collembola. Lubbock (10) quoted Packard's statement that the eggs of *Isotoma Walkeri* were laid singly, or in small scattered groups, on the damp under surface of bark. Macnamara (11) mentioned that oviposition apparently took place in the dark as the operation had never been observed. He also stated that an English writer in 50 years' study of these insects had never succeeded in observing oviposition.

With *S. viridis*, the operation has been seen at various times of the day. The eggs are laid in groups or mounds on the surface of the soil or on debris or stones on the soil. After selecting a suitable spot the female depresses its head and raises the end of the abdomen. At the same time an egg emerges and almost immediately assumes a spherical shape. The insect remains in this position with the egg adhering for one or two minutes. Then a drop of thick brown fluid exudes from the anus and quickly increases in size. The anal opening is posterior to the vagina, and, owing to the position of the body, the growing drop soon comes in contact with the egg, which is still adhering where it emerged. The egg immediately becomes incorporated in the brown fluid, and is then worked round and round until it becomes completely hidden, the process requiring about a minute. The abdomen is then depressed, the insect grips the soil with its claws, and with a slight pressure and circular movement of the tip of the abdomen, firmly presses the egg in position on the soil. This takes from a third to half a minute. The whole process, from the raising of the abdomen as the egg emerges to the completion of placing the egg (now covered with a coating similar in colour to the surrounding soil), occupies about three minutes.

The source of the brown mud-like fluid used for covering the egg was investigated. It was found to be soil taken in through the mouth. The habit of eating soil is not restricted to the oviposition period and will be referred to later. However, during the laying period the female eats much more soil than at any other time, and when one egg is placed in position she walks away to partake of soil before another is laid. The amount of soil used by a female to cover 85 eggs is approximately five times her own weight. Since one female may lay more than one egg mass, and since a certain amount of soil is eaten during early life, one can realize that during the course of its life one insect consumes a relatively large amount of soil. By reason of the soil-eating habit, oviposition is a lengthy process. One female which at 9.40 a.m. had deposited 29 eggs was still laying at 3.30 p.m. Over 80 eggs were laid in the batch, an average of less than ten per hour.

Eggs are laid in masses containing any number of eggs up to 85, though the number is usually from 55 to 65. The mass forms a small dome-shaped mound, which, on an average, is about 3 mm. across and 2 mm. high. In the middle there may be two or three layers of eggs. The total number which may be laid by an individual is at least 117. Four females in a tube laid, during the course of their lives, 471 eggs, or an average of 117.7 per female. The insect may lay two batches, and the evidence in some cases points to a probability of more than two. Records of the interval which elapsed between the laying of two egg masses under laboratory conditions were 10, 12, 16, 17, and 19 days respectively. Under spring conditions, it was from 10 to 12 days. The average is probably from 14 to 16 days.

The age at which egg-laying begins was found, under laboratory conditions, to be 22, 24, 30, 42, 42, 50, and 54 days respectively, varying considerably even with insects reared from the same egg mass and kept in the same tube till the time of the first laying. In one such batch it ranged from 30 to 54 days.

Hatching.—Just before hatching the egg swells and the chorion breaks around an equator. Under ordinary circumstances, when the egg is covered with soil, the split widens more at one part, and one half of the shell separates from the other as if it were hinged. When the halves have separated, the nymph, enclosed in a shiny embryonic membrane, is seen in one half. The outlines of the head, the eyes, and the antennae, are clearly visible. The antennae are freed first, and gradually the insect liberates itself completely and leaves the shell.

The duration of the egg stage is dependent on the moisture of its immediate environment—the soil. Under ordinary conditions of fairly constant moisture, it occupies from eight to ten days. However, under dry conditions, eggs have been kept alive for 271 days, without hatching (*vide* Expt. 2). After that period they received moisture, and hatching began twelve days later, continuing for 24 days. This observation indicates the variation that may occur in the duration of the egg stage. How long such eggs are capable of remaining alive is not known. It would appear that the coating of soil round the egg assists in the hatching by distributing moisture over the whole of the egg and by the formation of a "hinge."

Nymphs.—First instar nymphs are pale yellow except for the eyes, which are black, and the antennae, the third and fourth segments of which are pale lavender, the third being lighter than the fourth. The head is large in proportion to the body. The length of a newly-emerged nymph, from the anterior end of the head to the posterior tip of the abdomen, is 0.48 mm.; and the length, to the tip of the furcula when extended, is 0.70 mm. The third antennal segment measures 0.08 mm., and the fourth 0.21 mm., the first and second being shorter than the third. The width of the head is 0.21 mm., and the abdomen 0.22 mm. The ventral tubes of the first instar are functional soon after its emergence from the egg.

The moulting of the early instars has not been observed. From daily records of the size of nymphs it would appear that there are at least six or seven moults up to the time laying begins. The early stage nymphs differ very little from the first instar. During later instars the colour usually becomes greenish or yellowish brown, generally with an increasing amount of black in the dorso-lateral region. Moulting of later instars has been observed on foliage, on soil, and on the glass of the experiment tubes. Those which moulted on glass had the posterior end of the abdomen attached to the glass by a yellowish mass that was utilized by the insect in freeing itself from the old skin as it dragged itself forwards. Occasionally insects feed on their moulted skins.

The Adult.—The adult was very briefly described by Linnaeus (9) and Geoffroy (5), a more complete account being given by Lubbock (10). Schott's description (14) refers to the yellowish variety which becomes more abundant than the green and black forms as the warm weather approaches in September and October.

The more typical forms found during the winter have the ground colour yellowish green, and the fourth antennal segment somewhat lavender coloured. On the head, just behind the eyes, is an irregular fuscous patch. The dorsum of the thorax is fuscous yellow, and the dorso-lateral part irregularly fuscous. On each dorso-lateral region of the abdomen is an irregular longitudinal black band, while a few black markings in the mid-dorsal region give to the dorsal yellowish area the appearance of two longitudinal markings.

The sexes are difficult, if not almost impossible, to distinguish by the unaided eye. Copulation has not been observed.

2. Life History.

Observations were begun in July, 1925, and carried on until September, 1926, when the author left South Australia. Thus, the observations covered one complete year, but for five months of the period "fleas" were not in evidence. They make their appearance just after the first winter rains, usually in April, and are present in the fields and pastures throughout the winter until the beginning of the summer. In October there is a very marked decrease, hot dry winds accelerating their disappearance. By the beginning of November, they are difficult to find, and soon afterwards completely disappear.

Lea (7) says, "They disappear with the first spell of hot weather (except in very moist situations), so that between October and April they are seldom in evidence." Apparently he was of opinion that some of them lived through the summer in moist situations. However, as far as my observations go, this does not seem likely at Adelaide, and if any nymphs or adults do manage to survive the summer, their numbers are so small as to be negligible. The majority of those appearing in the autumn have another origin, namely, from over-summering eggs.

From observations in the field and trials in the laboratory, it was found that the main factor controlling hatching of the eggs was soil moisture. If there is not sufficient present, no hatching occurs. Further evidence was gained in the early summer, when it was noticed that after more than a week of hot dry weather, there were practically no very young nymphs in the plots. Then rain came, and seven or eight days later the plots were literally swarming with first instar nymphs.

The condition of eggs in dried soil is as follows:—On removal of the soil surrounding them they appear as balls, which have been pushed in as far as possible on one side, so that the invaginated part of the shell appears to be almost touching the other side. On the addition of water, the egg absorbs moisture, and in a minute regains its spherical shape. In order to test out the idea that over-summering took place in the egg stage, Expts. 1 and 2 were conducted. Expt. 1 was carried out under field conditions, and the eggs were left exposed to the weather throughout the summer. Expt. 2 was performed in the laboratory, and the eggs were hatched 300 days later by the addition of water to the soil on which they had been laid. Both experiments demonstrate the great resistance of eggs to heat and lack of moisture, and their dependence on moisture for hatching.

The South Australian summer is very dry, the wet season occurring in the winter, over 80 per cent. of the yearly rainfall being in the period April to October inclusive. In the summer 1925-26, only 1.70 inches of rain fell during the five months November to March. Under ordinary conditions the surface soil is quite dry in summer, and all herbaceous plants die. Lack of moisture, by preventing hatching, would eventually result in the disappearance of fleas from the fields. But it also affects the living insects by making it impossible for them to obtain their ration of soil, it being very difficult, if not impossible, for them to eat soil when it is dry. However, observations in the laboratory on insects which were kept provided with food and moist soil, and also field observations, indicate that lack of air moisture mainly affects the insects directly.

To what extent temperature, apart from its relation to relative humidity, affects these soft-bodied insects has not yet been ascertained, but it is very evident that lack of moisture, together with increasing temperature, has such an effect on the metabolism of all stages, that the undeveloped egg is the only stage capable of resisting these adverse conditions.

3. Feeding Habits and Host Plants.

Smynthurus viridis causes considerable damage to the foliage of many winter fodder plants, particularly lucerne and clovers, and also to the cereal crops, wheat, oats, and barley, when the latter are just through the ground. A severe attack on lucerne gives the field a scorched appearance. The "fleas" feed with a bite which is probably best described as a combination of gnawing and chiselling. They do not usually make holes right through the leaf, but consume one epidermis and the underlying mesophyll tissue down to the other epidermis. On some plants they feed on the upper leaf surface, and on others, on the lower. With Cape weed (of which they are very fond) and subterranean clover, they feed on the upper surface, which is much smoother than the lower, which is hairy. On lucerne and thistle they feed on the under surface. It was noticed that crimson clover (which has abundant hairs on both leaf surfaces), though growing near subterranean clover which was seriously damaged, was only lightly attacked. On some hosts, notably hop trefoil (*Medicago lupulina*), wild trefoil (*M. sp.*), lucerne (*M. sativa*), and *Trifolium repens*, an area of dead tissue many times the size of the actual damage may develop round the scene of attack.

The following list of host plants is compiled from observations at the Waite Institute, and from answers supplied by agriculturists to a questionnaire.

Host Plants.—Cape weed or South African dandelion (*Cryptostemma calendulaceum*), subterranean clover (*Trifolium subterraneum*), strawberry clover (*T. fragiferum*), hop trefoil (*Medicago lupulina*), wild trefoil (*M. sp.*), burr medic (*M. denticulata*), birdsfoot trefoil (*Lotus corniculatus*), oats, wheat, barley; all varieties of lucerne (*Medicago sativa*) grown at the Waite Institute, including the following varieties:—South African, Hunter River, Patagonian, Provence, Peruvian, Japanese, Spanish, Persian, Grimm, Salt Lake City, and Marlborough; crimson clover (*Trifolium incarnatum*), red clover (*T. pratense*), white clover (*T. repens*), cluster clover (*T. glomeratum*), alsike clover (*T. hybridum*), Shearman's clover (*T. resupinatum*), cow grass (*T. pratense perenne*), Bokhara clover (*Melilotus alba*), narrow leaf clover (*Lotus angustissimus*), greater lotus (*L. major*); cabbage, pea, bean, potato, tomato, onion, turnip, carrot, mangold; flowering plants, including sweet pea, ranunculus, carnation, geranium.

Smynthurus has been recorded on the following, but they are not seriously affected by it:—Sweet vernal (*Anthoxanthum odoratum*), Danish fescue (*Festuca sp.*), crested dogstail (*Cynosurus cristatus*), tall oat grass (*Avena elatior*), Timothy (*Phleum pratense*), sheep's fescue (*Festuca ovina*), Waipu brown top (*Agrostis tenuis*), hard fescue (*Festuca duriuscula*), Kentucky blue grass (*Poa pratensis*), reed canary grass (*Phalaris arundinacea*), Wimmera rye grass (*Lolium subulatum*), meadow grass (*Poa trivalis*), red top (*Agrostis alba*), cocksfoot (*Dactylis glomerata*), meadow foxtail (*Alopecurus pratensis*). Lea mentions that stinging nettle grown near lucerne or Cape dandelion is also attacked.

In addition to being a foliage feeder, *Smynthurus* is also a soil eater. This was first observed in connexion with oviposition, and has already been described. It would appear that if females which are ready to lay are prevented from obtaining soil, oviposition is delayed. Smynthuri collected in the field were kept in a tube with food, but they did not lay, and appeared to have no desire for feeding. On the fourth day, a small amount of moist soil was added to the tube. Five minutes later the insects were feeding on the soil and, as far as could be ascertained, remained on it almost continuously during the succeeding hours. Three hours after feeding, both were laying. It appears that soil is also required during the earlier part of the insect's life. Absence of soil affects growth as well as egg production (*vide* Expt. 4).

An experiment to compare the responses of a first instar nymph to food and soil, showed that during the first twelve hours of its life, the attraction to soil was much stronger than the attraction to food. During that time the nymph was several times found on soil, which it consumed, so that a dark colour could be seen throughout the whole of the alimentary canal. During the whole of this time the nymph was never seen on the food provided.

The method of observation was as follows:—A newly-emerged first instar nymph was placed in the middle of a piece of 8-mm. bore glass tubing, 22 cm. long. Clover leaves were placed 1 cm. from one end, and moist soil was placed 1 cm. from the other end. The ends were closed with cotton wool and the distance between food and soil divided into four portions, each 5 cm. long. The tube was covered with a dark cloth. Records of the position of the nymph in the tube were made every half hour. There were repeated journeys to the soil end of the tube in the first twelve hours, while the nymph was not seen once in the section near the clover. On the second day, the nymph was several times found in the food end of the tube, but oftener in the soil end. On the third day, the nymph spent more time in the clover end of the tube, and was found several times on the clover. Fresh food and soil were provided daily. It would appear, then, that for the normal physiology of the insect during its early life, soil is a greater necessity than green food.

Eggs which are not completely covered with soil are sometimes eaten by females. This habit is particularly noticeable in females which have been kept without food and whose eggs are quite naked. Other feeding habits include the occasional eating of dead companions, which has been observed even in first instar nymphs, and also the occasional eating of moulted skins.

4. Natural Controls.

The most important natural control is that of the weather, particularly in the early summer. Should hot weather be experienced suddenly, large numbers of nymphs are killed off before they can lay, and many eggs partially developed are also killed. A large proportion of eggs collected in the field in the early summer for experimental purposes were found to be useless, as they contained dead embryos. It appears to be only the undeveloped eggs which are capable of surviving the summer heat.

The following predators have been observed at Adelaide:—Two species of spiders (immature) predaceous on nymphs and adults; an undetermined Collembolan which attacks nymphs at least; *Paederus cingulatus* Macl. (Staphylinidae) (Fig. 9)(1); *Pheidole ampla,* For. (Formicidae). This last is a small black ant which builds its nest in the ground. The ants and spiders carry off struggling "fleas" and take them down into their nests.

5. Distribution.

Lubbock (10) states that *S. viridis* occurs in Sweden, Switzerland, France, England, and Germany. Dr. Marshall has informed me that, in addition to being common throughout Europe, it is also recorded from Nova Scotia,(2) and the Argentine. It occurs in the south-western part of Western Australia, and is well known to South Australian agriculturists. In order to obtain some idea of its distribution, circulars were sent to all the South Australian agricultural bureaux.(3) Between 60 and 70 of these circulars were returned, and, with a few extra records, a very good idea of the distribution in question was obtained. It extends from Melrose 140 miles north of Adelaide, to Mount Gambier 240 miles south-south-east of Adelaide, or a total range of nearly 380 miles. It is also recorded from the Yorke and Eyre Peninsulas. This distribution corresponds very closely with the area which receives an annual rainfall of 15 inches and over. Of 49 localities from which "flea" was recorded only two had a rainfall below 15 inches. These were Kilkerran South on Yorke Peninsula, with an annual rainfall of 14.5 inches, and Murray Bridge, with a rainfall of 14 inches. However, the soil at Murray Bridge, where the "flea" occurs, is heavy river-flat soil with good moisture-retaining qualities, and it receives additional moisture by irrigation.

At Adelaide, the soil where *Smynthurus* occurs has a slightly acid reaction, the p.H. value being from 6 to 6.7. Expt. 5 shows the effect on the insect's life of an alkaline soil with a hydrogen ion concentration of 7.45. Professor J. A. Prescott (13), of the Waite Institute, working on a soil survey of South Australia, has found that there is a close correlation between soil p.H. and rainfall, the higher the rainfall the more acid the soil, and the lower the rainfall the more alkaline the soil, the only exceptions to this generality being the irrigated lands such as

(1) Identification secured through the courtesy of Dr. G. A. K. Marshall, Director of the Imperial Bureau of Entomology.

(2) Dr. A. Gibson, Dominion Entomologist of Canada, informs me that he is not aware of the existence of *S. viridis* in Nova Scotia, but that *S. hortensis* occasionally causes trouble there.

(3) Through the courtesy of Mr. Gregory, Secretary of the Central Bureau, Adelaide.

Murray Bridge, which have an acid reaction, whereas the soils of localities with a rainfall similar to that of Murray Bridge and not irrigated are alkaline. (The p.H. value of the Murray Bridge soil is from 4.7 to 6.4.) This information is interesting in view of the effect of soil p.H. on the insect's life. It shows that rainfall, while providing the necessary soil moisture for the insect, also has a further effect on its physiology through the soil p.H., with which it is correlated.

6. The Effect of Meteorological Conditions.

It was early seen that meteorological conditions had a pronounced effect on the life of the insect. The latter's disappearance in the summer and its reappearance in the autumn have already been mentioned. In general, we see the following conditions operating:—With the approach of winter there is an increase of rainfall and a decrease in temperature, resulting in an increase of relative humidity. The soil becomes moist, herbage develops, and the power of the air to take up moisture is decreased. All these conditions favour the development of *Smynthurus* eggs, and supply suitable conditions of atmosphere, food, and soil moisture, for the life of the insects. At the approach of summer, all these factors are reversed; rainfall decreases; temperature rises; and the atmosphere develops a high power for absorbing moisture. The result is a cessation of all activity on the part of the insect.

It has been seen that egg hatching is the chief indication of the commencement of seasonal activity, and that the most important condition affecting hatching is soil moisture. The main factors influencing the latter are rainfall, temperature, air moisture or relative humidity, wind, and the constitution of the soil, particularly its mechanical properties. The mechanical constitution of the soil will probably be found to have a marked influence on distribution. At present the nearest approach to obtaining a single measure of these various factors appears to be the measure of the evaporation power of the air, an examination of the graphs (Figs. 1 and 2), indicating how close is the correlation between it and insect activity. There is a general correlation between individual factors and activity. A more detailed discussion must be reserved until a later occasion, when more than merely monthly averages are available. From the graph (Fig. 1) it appears that the maximum air temperature gives a good correlation. Unfortunately, the relative humidity records for the whole period over which observations were made are not available.

Field observations indicate that there is a correlation between rainfall and insect activity, but more accurate data than monthly averages will be necessary to demonstrate it. The rainfall graph (Fig. 2) shows a precipitation for February, 1925, higher than that at which hatching ceased, but as far as is known hatching did not occur. This high rainfall was confined to a single day. The temperature was high, and the soil would very soon have dried out. Although the relative humidity was high, the evaporation power of the air also remained high. It appears, then, that evaporation power of the air expresses, better than any other individual measurement, the factors operating to affect seasonal activity. By using hatching as an indication of insect activity, it appears that the lucerne "flea" will become active at Adelaide when climatic conditions are such that the daily evaporation from a free water surface becomes less than 0.133 inch, and hatching will cease when the evaporation becomes greater than 0.133 inch.

7. Experimental Work.

Experiment 1—To test the over-summering of eggs.—Into each of three porcelain pots, 15 inches deep and 10½ inches in diameter, about 10 inches of sifted soil was placed, and on top of this was added 3 or 4 inches of sifted soil which had been steam sterilized, in an autoclave, at a pressure of 2 atmospheres, for half an hour. This precaution was taken to eliminate the possibility of living *Smynthurus* eggs being present.

The first pot (C) was kept as a control. On the surface in another (No. 1) several egg mounds, collected on dry soil in the field, were placed. In the centre a glass tube was sunk nearly to the level of the soil, and three or four egg masses placed in it. This precaution was taken so that the position of at least some of the eggs would be known accurately at the end of the summer.

In another pot (No. 2) were planted a few Cape dandelions, which had previously been washed thoroughly to free them from any trace of soil or insects. The idea was to simulate in this pot a weedy field. As the summer advanced the weeds would die, but their dead leaves would give the surface soil some kind of protection from the direct heat of the sun. Around each pot was placed a band of "Bird lime" 5 inches wide to isolate it, but this was later found to be unnecessary. The sides of the pots were vertical and glazed, and it was noticed that, although the insects could hold on to the smooth surface, they could not move more than one or two steps without falling to the ground.

The experiment was started on the 22nd of October, 1925, when "fleas" were becoming very scarce in the field. The egg mounds were not placed in pot No. 2 until the 2nd of November, when the weeds which had required watering had become established. The pots remained in a wire-netted enclosure, exposed to the weather throughout the summer, which, for the most part, was hot and dry. During the latter part of November and the beginning of December, during a heat wave, the shade temperature rose to 110° F. On a day when the shade temperature was 104° F., the sun temperature was 165.7° F., so that when the shade temperature was 110°, the sun temperature would probably have been in the vicinity of 170° F. As the eggs are laid on the surface of the soil, the thin soil coating of the eggs at least would be subjected to the highest temperature reached by the surface soil.

When examined on the 27th of February, 1926, the surface of the soil in the experimental pots was found to have been beaten down by heavy rain, which had fallen a week previously, the location of the eggs becoming indistinguishable.

The first winter rains began on the 23rd of April, 1926. For a week the weather was variously showery, dull, and bright. Then rain became more constant, and 1.12 inches were recorded on the morning of the 1st of May. On this day nymphs were found in the clover pots, and, on the following day, in pot No. 2, which had had weeds in it. Very young nymphs were also found in the fields and pasture. Of those seen, the largest were observed in the clover pots, which was probably to be accounted for by the presence of a quantity of foliage, which would protect the soil from excessive evaporation, and thus provide continued moist conditions for the developing eggs from the time of the first rains. No nymphs were observed in either the control pot or pot No. 1. The questions arises—Were the eggs when placed on the soil already incapable of development, or were they killed during the excessive heat of the summer? Eggs were recovered from the central area surrounded by the glass tube, and were found to contain well-developed embryos. They had probably begun to develop while there was moisture available in the spring, and had then died, through lack of moisture, on the approach of summer. The question as to whether any over-summering eggs are killed by summer heat is a matter still to be investigated. Whether occasional rains in the summer initiate egg development has also to be determined. At least sufficient eggs remain in a condition favorable for development on the arrival of winter rains, and thus are able to perpetuate the species.

This experiment, and experiment No. 2, clearly demonstrate the method by which *Smynthurus* passes the summer. They also show the dependence on moisture for development, and demonstrate the ability of eggs to resist very considerable heat under dry conditions.

Experiment 2—To hatch artificially eggs which had over-summered in the laboratory.—The eggs used in this experiment were laid in the laboratory on the 22nd of August, 1926, i.e., over a month before hatching ceased in the field. They remained indoors in the glass tube in which they had been laid until the 11th of May, 1926—271 days later. The tube was closed with a cotton plug throughout this time, and no moisture was added until the 11th of May, 1926, when the experiment was started. The room in which these eggs were kept during the summer was subjected to the worst effects of the hot dry north winds of that period of the year. The lives of fifteen eggs in this experiment were carefully noted. At the beginning of the experiment, the eggs were placed on ordinary sifted soil, from fields where *Smynthurus* occurred,(1) in a glass excavated block, loosely covered with glass to prevent excessive evaporation. A drop or two of distilled water was added when the soil showed signs of drying, which was nearly every day. Observations were made daily and, during the hatching period, two or three times a day. Part of the process of hatching of nearly every egg was thus observed. The first hatched 12 days after the initial watering of the 11th of May, and subsequent hatchings took place as follows:—Two at 13 days, one at 15, one at 18, two at 19, one at 25, two at 29, one at 30, two at 32, and the last two at 35 days (all periods measured from the 11th of May).

The experiments demonstrated that eggs could remain alive for a considerable time, under adverse conditions, without moisture. It also showed that soil moisture was the main factor in the development of the eggs, and explained why the "flea" disappeared in the summer and reappeared soon after the first autumn rains of any consequence. The results of these two experiments leave no doubt as to the over-summering of *Smynthurus* in the egg stage.

Experiment 3—To observe the effect of absence of soil.—Twenty *Smynthuri* collected in the field on the 25th of May, 1926, were divided.

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(1) This was considered necessary since it was suspected that different soil environments affected the egg period and the hatching.

and half placed in a large glass tube with moist soil,(2) and lucerne, variety Marlborough, for food. The other half (A) were placed in a similar tube with the same variety of lucerne but without soil. The tubes were closed with fairly loose cotton wool plugs, and daily records were kept of the number of eggs laid and the number of insects found dead. The insects were removed to clean tubes and given fresh food nearly every day, and in the case of the control tube (C) fresh moist soil was given regularly. In (A), the eggs were laid naked on the glass or on leaves of the food. Occasionally, females were found eating their own eggs soon after having laid them. In such cases, a very fair idea of the number laid could be obtained by counting the shrivelled remains of the shells. After the experiment had been in progress three weeks it was found necessary to adopt another food plant. Clover (*Medicago denticulata*) was used in both tubes, and the change did not seem to affect the insect materially.

Although at the beginning of the experiment, there was practically no difference as regards size between the insects in the two tubes, after two weeks it was very evident that those in the control tube were much larger (*vide* Expt. 4). A comparison of the results from each batch gave the following information:—The absence of soil from (A) did not appear to affect the length of life, since the total number of insect days lived by those in the control tube was 327, or an average of 32.7 per insect; while in (A) they were 330, an average of 33 per insect. However, there was a marked decrease in the number of eggs laid in (A), the average being 0.42, while the controls averaged 0.94 per day; so that (A) produced only 45 per cent. of the number laid by the controls. It is realized that these results alone could not be considered very significant, since the insects used in the experiment were not all of the same age. But it is interesting to compare the results with those obtained in Expt. 4, where the insects in tube (A) were prevented from obtaining soil throughout their lives.

Experiment 4—To ascertain if soil is essential.—First instar nymphs, just emerged from eggs collected in the field, were used in this experiment, which was started on the 10th of June, 1926. Four nymphs were placed in one tube (C) with damp soil and clover, and four in another (A) with food but without soil. During the second week, it could be seen that the controls had grown more and had a rotund, well-fed appearance; whilst those without soil were smaller and "pinched," did not feed well, and were often observed inactive for a considerable time. At the end of three weeks, all insects were measured, the average length of the controls being 1.94 m.m. as against 1.30 m.m. in the other case. The former thus averaged more than one and a half times the length of those deprived of soil. The smallest specimen in (C) was 1.25 times as long as the largest in (A).

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(2) Unless otherwise stated the soil used in all control experiments was ordinary sifted clay loam soil from the fields at the Waite Institute, where lucerne flea was known to thrive.

A typical analysis of such soil is as follows:—

Mechanical Analysis. (Percentage taken on total dry matter.)		*Chemical Analysis.*	Per cent.
Clay	14.2	$Al_2O_3 + Fe_2O_3$	7.69
Fine silt	24.2	CaO	0.22
Silt	21.9	MgO	0.48
Fine sand	33.5	K_2O	0.47
Coarse sand	2.1	P_2O_5	0.043
Fine gravel	0.3	Total nitrogen	0.091
Loss on ignition	3.7	p.H. value	6.7
Total	99.9%		

From this time, at intervals of three or four days, all insects in both tubes were measured, the relative average length of the insects being indicated in Fig. 3. (The widths of the columns are arbitrary, and not to scale.) The point which is brought out clearly is that the size of the insects (as shown by the length from the anterior of the head to the tip of the abdomen) in the tube without soil is consistently smaller than that of the controls.

Fig. 4 indicates the length of life of each insect in each tube. The lack of soil did not appear to affect the duration of life, for in the control four insects lived a total of 279 days, or an average of 69.7 days; while without soil four insects lived a total of 278 days, or an average of 69.5 days.

There was a marked difference in egg-production by the insects in each batch (*vide* Fig. 6). In the control a total of 471 eggs were laid by the four insects during their complete life, but in the tube devoid of soil only 84. During the egg-laying periods, the insects from both batches were confined, for portion of the time, in separate tubes, in order to ascertain the number of females present. In the control, all four were females and uniform in size. In the other batch one was probably a male. It was much smaller, darker, and, as far as could be observed, it never laid.

The main data from the experiment are set out in the following tables. (C = control. A = batch deprived of soil.):—

Batch.	Insects.	Total Life in Days.	Average Life in Days.	Females.	Total Eggs.	Average number of Eggs per Female.
C	4	279	69·7	4	471	117·7
A	4	278	69·5	3	84	28·

Batch.	Egg-laying Period (days).	Time to first Laying (days).	Eggs per Female Day.	Percentage Egg-production.
C	40	30	1·69	100%
A	18	44	0·40	25%

It will be seen that egg-laying began fourteen days later in (A) than in (C); that the period during which it occurred in (A) was less than half that of (C); and that, although laying commenced fourteen days later in (A), it was completed before it had ceased in (C).

The main points which the experiment seems to indicate are—(*a*) soil is not essential for life (at least for one generation); (*b*) absence of soil did not seem to affect the duration of life; but it (*c*) resulted in less growth; and (*d*) reduced egg-production to 25 per cent. of that in the control.

Experiment 5—To observe the effects of changed hydrogen-ion concentration of the soil.—The soil at the Waite Institute, where most of the field observations were carried out, had a slightly acid reaction (p.H. 6.0 to 6.7). The present experiment was planned to observe the effect on the insect's life of changing the soil reaction from acid to alkaline.

In the control tube eight first instar nymphs were placed with ordinary sifted soil (p.H 6.7), which had been moistened with distilled water. Eight more first instar nymphs of the same age were placed in a second tube with similar soil, which had been made slightly alkaline by the addition of calcium carbonate, the p.H. then being 7.45. Clover was used as food in both tubes.

The difference in duration of life in the two tubes was very small. In the control (C) eight Smynthuri lived a total of 308 days, or 38.5 per insect. In the other batch (A), seven—one was lost during the experiment—lived a total of 257 days, an average of 36.7 per insect. Fig. 5 shows graphically the length of life of each.

There was a slight difference in size between the insects in the two tubes, those in the alkaline batch being slightly smaller.

The results were as follows :—

Batch.	Number of Insects.(1)	Total Life in Days.	Average Life in Days.	Total Eggs Laid.	Average.	Eggs per Insect Day.
C	8	308	38·5	630	77·5	2·04
A	7	257	36·7	128	18·3	0·5

Batch.	Time to Egg-laying.	Egg-laying Period.	Egg Production.
C	22 days	24 days	100%
A	23 days	15 days	24%

(1) At most there were three males in each batch. In (C) one of these died early before egg-laying

There was a striking difference in the number of eggs laid per egg-mound in each batch. In (C) six mounds contained over 60 eggs each, the highest number being 84; whilst in (A), the maximum per mound was only 34.

It will be seen from the table that in (A) egg-production was only 24 per cent. of that in the control. Fig. 7 graphically represents the egg-production by the insects reduced to four insects in each batch for comparison with Fig. 6.

It is interesting to compare the controls in Figs. 4 and 5, which indicate the duration of life in Expts. 4 and 5 respectively, drawn to the same scale. It will be seen that life was much shorter in Expt. 5 than in Expt. 4. Expt. 5 was carried out in the early summer (20th September to 8th November) and hot dry conditions prevailed towards the end. Such conditions, which in the field kill off all nymphs and adults, leaving only eggs, probably had the effect of cutting short the normal life of the insects. Expt. 4 was carried out during the late winter (10th June to 31st August). Although the average life in Expt. 5 was much less than in Expt. 4 (39 days as compared with 70 days), the rate of egg-production reckoned in insect days was much higher. In Expt. 4 it was 1.69 eggs per insect-day when all the insects were females, whereas in Expt. 5 it was 2.05 with probably two or three males included, which would thus tend to give too low an average. This shows that at the approach of summer the rate of egg-production increased more than 21 per cent.

8. The Role of Soil in the Insect's Physiology.

It is too early to come to any definite conclusions concerning the role which the soil plays in the physiology of *Smynthurus*. That there is in the soil some factor (or more than one) which has a very marked effect on the insect's life is very evident. What the exact nature of this "accessory physiological factor" is, has yet to be determined. Without further experimental evidence one cannot do more than speculate. It is certain that the soil is not merely serving as roughage, for in batch (A) of Expt. 5, the mechanical constituents were similar to those of the control. It would appear then that the soil factor is concerned with nutrition.

Arrhenius (1) found that earthworms could live only in soil whose p.H. value was in the vicinity of 6 and 7. In the case of *Smynthurus*, the effect of changed soil conditions has not been quite so profound, but the comparison is interesting. It seems that the changed hydrogen-ion concentration itself may not be the factor directly responsible for the altered physiology of the insect, but rather an indication of other changed factors. The change of soil p.H. may have the effect of so altering some soil substance concerned with nutrition, as to make it unavailable for the insect, and thus upset its normal functions. The various characteristics of the soil, physical, chemical, and biological, must all be considered in an investigation into this problem.

At present the situation stands as follows. If the p.H. of the soil can be so altered from what appears to be an optimum for the insect, and still be kept within a range advantageous to crop production, a very important step in the control of the insect will be made. Some growers have reported that where stable manure was abundant, "fleas" were bad; and some have noticed an increased attack after the application of superphosphate. The question as to how do these substances affect the insect thus arises. Do they affect it through the soil eaten, or do they affect it indirectly through the plants? It is a matter for future investigation to ascertain whether there is hope for ultimate control of the pest by methods other than the use of insecticides.

9. Recommendations.

The over-summering as an egg in the fields definitely establishes the fact that if "lucerne flea" is present in a field one season, it will be present there again next season, after the autumn rains have caused the hatching of the over-summering eggs. Any farm operation which causes the destruction of eggs present on the surface of the soil during the summer, or which results in deficiency of food for the insects in the autumn, will assist greatly in checking the pest. A judicious system of bare-fallowing, keeping in mind the life-history of the pest, will be of major importance. The best system of fallowing and crop rotation is a matter for future investigation, but with these suggestions, agriculturists will in the meantime, by their own observations and experience, be able to do a great deal along these lines.

It has been shown that an alkaline soil is detrimental to the insect and reduces its rate of reproduction, hence the application of lime to the soil should greatly assist in controlling the pest. As far as lucerne and the clovers are concerned, the crop will benefit directly from such application apart from its action on the "flea." All headlands should be kept quite free of weeds and growth of any kind, to minimize the spread from adjoining pastures. These recommendations may be summarized:—(*a*) bare fallowing in the rotation, (*b*) liming, (*c*) keeping headlands free of vegetation.

10. Acknowledgments.

I wish to acknowledge my indebtedness to the following members of the Adelaide University staff:—Miss E. D. Macklin, who carried through to completion Expt. 5 after I had left Adelaide; Professor J. A. Prescott, of the Waite Institute, for his active interest and for the preparation of soils for experimental work; and Professor Harvey Johnston for laboratory facilities; also to Professor O. A. Johannsen of Cornell University for reading through the manuscript.

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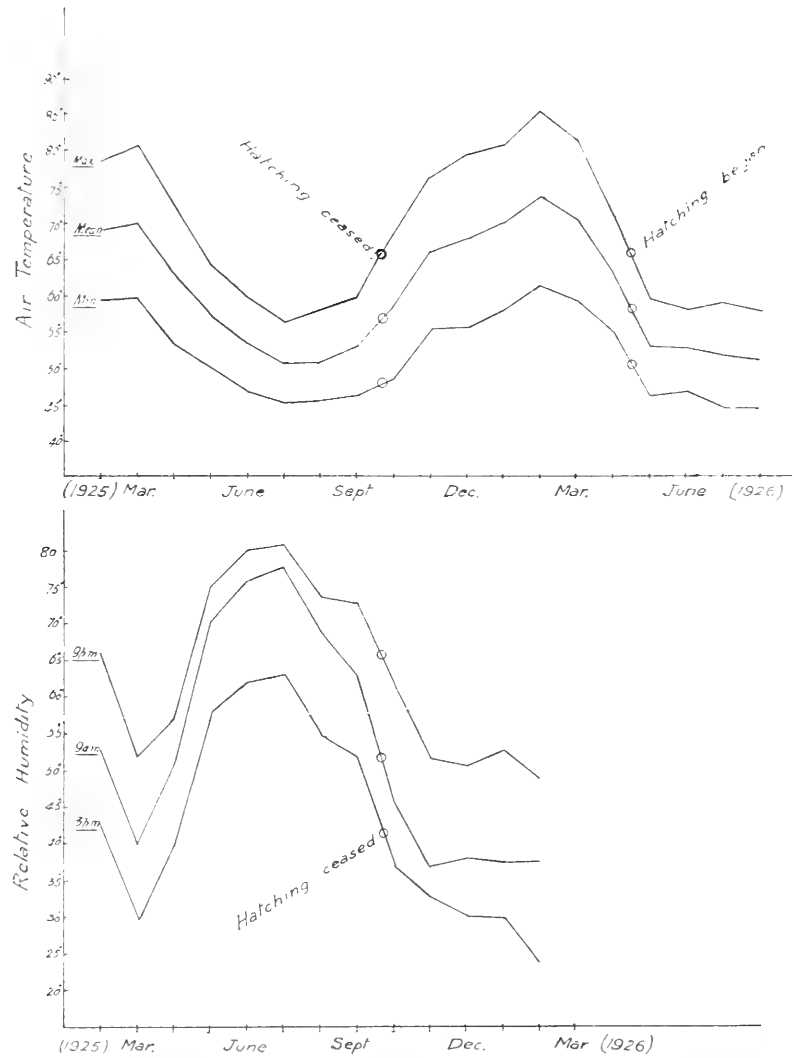


FIG. 1.—(*a*) Monthly average air temperature at the Waite Institute, Adelaide.
(*b*) Monthly average relative humidity for Adelaide (data supplied by Commonwealth Meteorological Bureau).

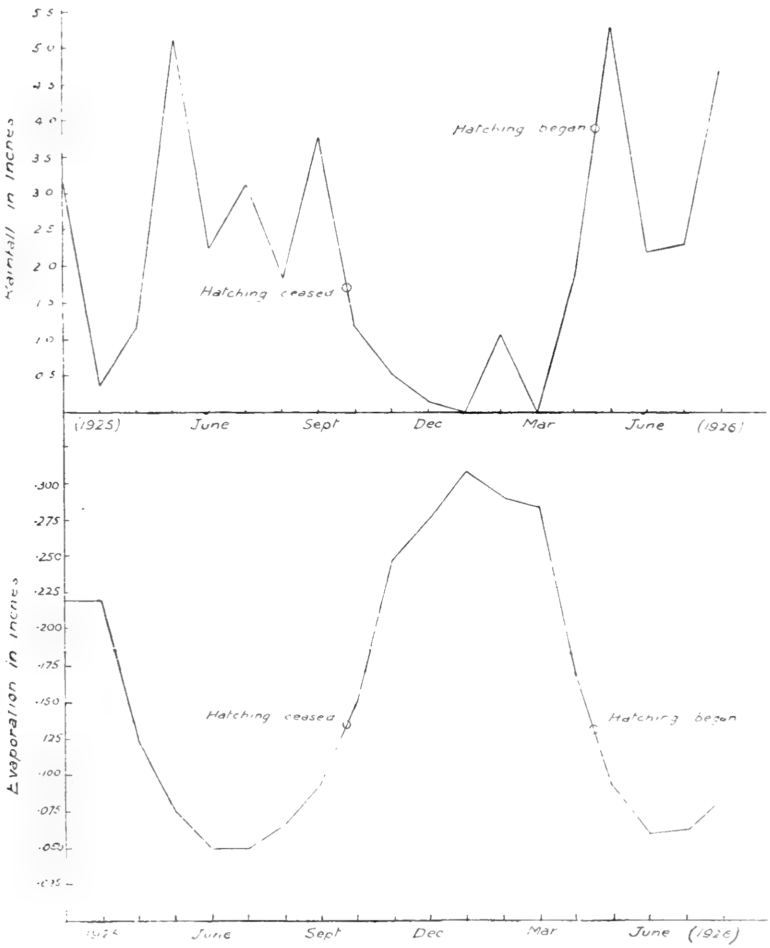
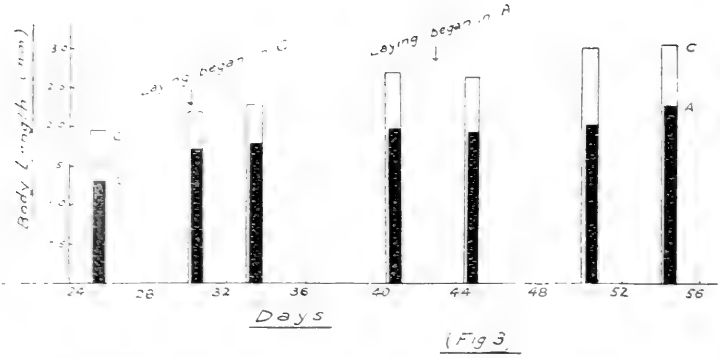


FIG. 2.—(*a*) Monthly rainfall at the Waite Institute, Adelaide.
(*b*) Monthly average evaporation per day



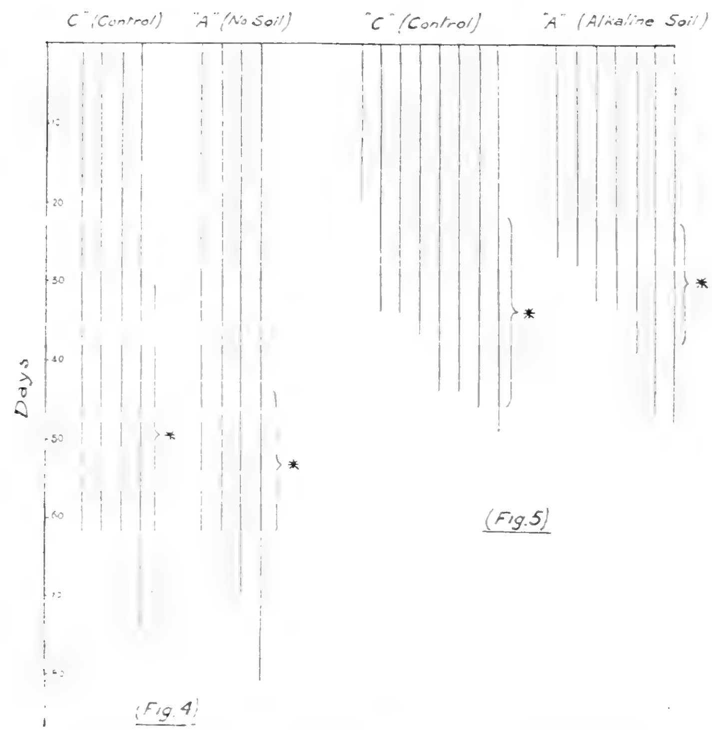
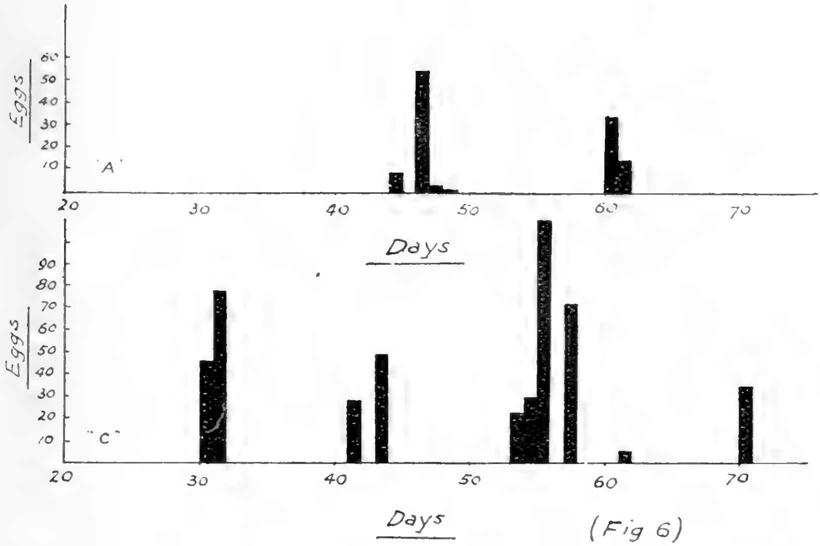


FIG. 3.—Graphic representation of growth with soil (C) and without soil (A).

FIG. 4.—Showing the duration of life of insects in Expt. 4.

FIG. 5.—Showing duration of life of insects in Expt. 5.

* Laying period.



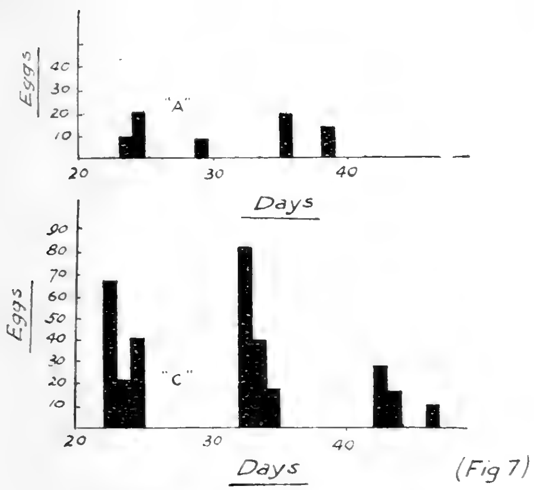


Fig. 6.—Graphic representation of egg production with soil and without soil. Calculated for four females.

(c) Control with soil.

(a) Without soil.

Fig. 7.—Graphic representation of egg production with soils of different acidities.

(c) Control with ordinary soil of p.H. 6·7.

(a) Alkaline soil of p.H. 7·45.

Eggs calculated for four females in each case.

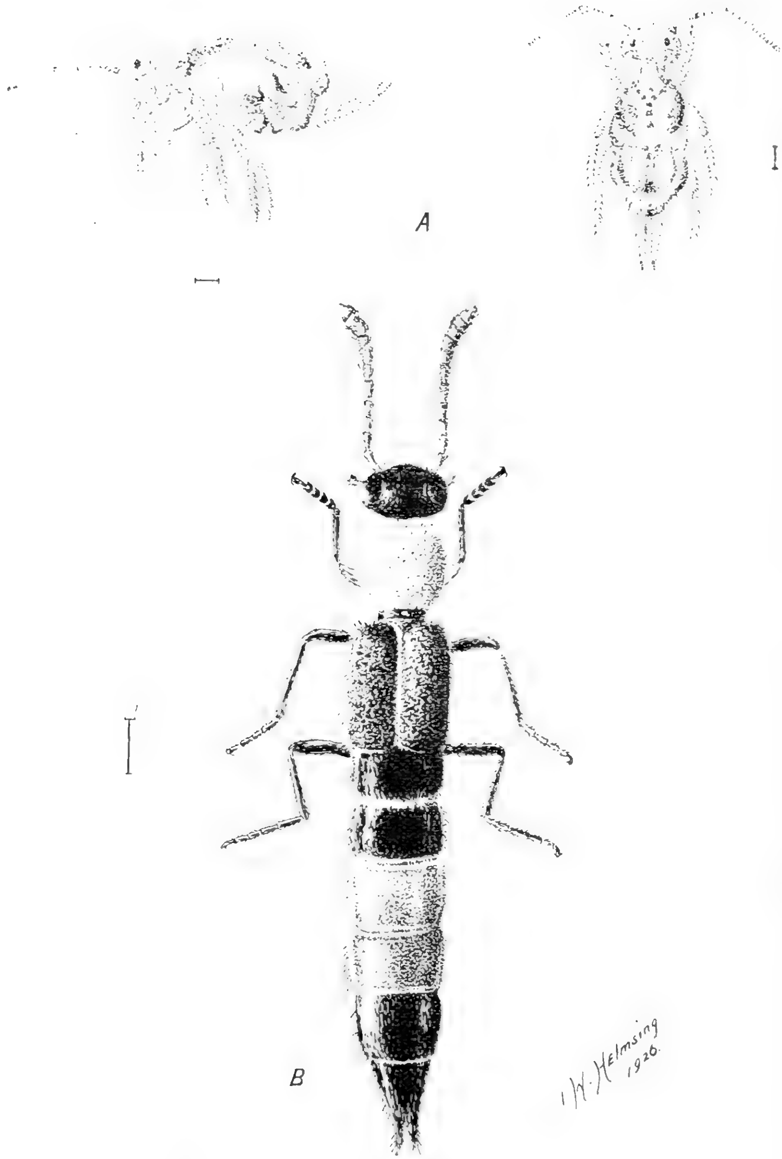


Fig. 8.—A *Smynthurus viridis* Linn.

B *Paederus cingulatus* Macl. Family—Staphylinidae, predaceous on *Smynthurus viridis.*

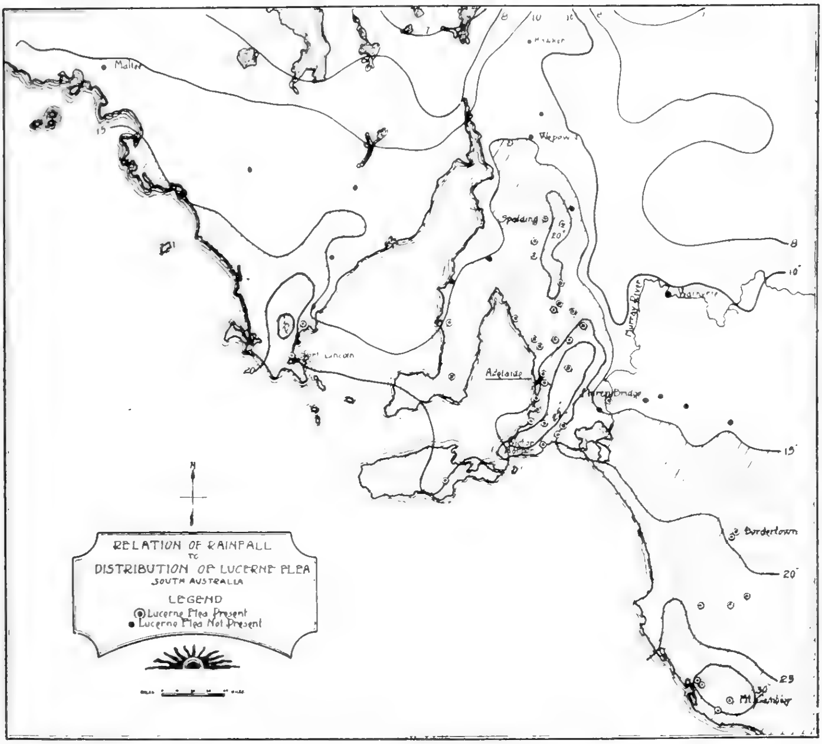


FIG. 9.—Relation of rainfall to the distribution of lucerne flea in South Australia.

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COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

LIVER FLUKE DISEASE in Australia: its Treatment and Prevention

By

I. CLUNIES ROSS, B.V.Sc.

MELBOURNE, 1928

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LIVER FLUKE DISEASE IN AUSTRALIA: ITS TREATMENT AND PREVENTION.

BY I. CLUNIES ROSS, B.V.Sc.,

Veterinary Parasitologist, Council for Scientific and Industrial Research.

1. What is Meant by Fluke Disease.

By fluke disease is meant those harmful effects caused by the presence of a flat leaf-like worm, the liver fluke,* in the bile ducts or liver tissue of the sheep or ox. Though cattle are frequently found infested by the liver fluke, the harmful effects caused in these animals are very much less serious than those in sheep. The information given in this pamphlet therefore applies primarily to fluke disease of sheep.

2. Its Economic Importance and Distribution in Australia.

It is hard to form an accurate estimate of the annual losses in Australia from fluke disease, since these may vary considerably from year to year in each State, and even in each district. It must be remembered also, that there must be included in the losses attributable to fluke infestation not only the actual mortality from this cause, but also the deterioration in the wool and mutton value of those sheep which are attacked but survive. In addition, sheep which are affected by fluke are much more susceptible to the attacks of other parasites such as stomach and lung worms. It can be definitely stated that over large areas fluke disease is the most serious disease affecting sheep, and throughout the whole of Australia the losses directly attributable to it are not less than £100,000 per annum, while in certain years this figure may be considerably exceeded. Fluke disease is of importance in four States of the Commonwealth, namely, New South Wales, Victoria, South Australia, and Tasmania. The areas most seriously affected are those of comparatively high rainfall, and these may occur either in high undulating country such as is found on the tablelands, or in the flat, coastal or lake country. Thus in New South Wales the disease occurs throughout the tablelands of the Great Dividing Range, grows less on the western slopes, and disappears on the plains. In Victoria, it is met with principally in the Gippsland district, parts of the Western and Central districts, and particularly along the valley of the Goulburn River. In South Australia, losses

* *Fasciola hepatica* (Linnæus 1758).

are confined to the wet South-eastern part of the State, while in Tasmania severe losses occur on the flat coastal areas of the North-east, the valley of the South Esk River, and in some of the river and irrigated land of the Midland Division. In Queensland fluke disease in sheep is very rarely seen, while it is practically non-existent in Western Australia.

That this disease, which is to a very large extent preventible, should continue to exact its toll is lamentable. Every stock-owner has his part to play in its eradication, and this pamphlet has been prepared with the object of assisting individual owners to do their utmost in that connexion.

3. The Life-cycle of the Fluke Parasite.

In order that the pastoralist may appreciate how fluke disease is spread and how it may be prevented, it is essential that he should understand the life-cycle of the parasite which causes the disease.

The adult parasite is a flat, yellowish or greenish-brown worm, leaf-like in shape, and about 1 inch long by ½ inch wide (Fig. 1). In a fluky liver the parasite may be readily demonstrated in the bile ducts. Here the worm lays its eggs, and each fluke may produce many thousands of eggs, which are minute yellowish-brown objects of the typical egg shape, and may be seen by smearing some of the bile from the ducts on a glass slide and then holding it up to the light. After leaving the liver the eggs mingle with the bowel contents, and so pass out of the sheep on to the pastures. Development now commences, but soon ceases unless the eggs have fallen into water or some moist place, for if the eggs become dry they soon shrivel up and die since it is only in water that they are able to undergo further development. On reaching water, development proceeds rapidly, and in eleven days in summer weather but much longer in cold weather, a minute embryo fluke is formed within the egg. The embryo now commences to make active movements so that a cap at the end of the egg is pushed up, and the little fluke, which is of microscopic size only, emerges and swims about rapidly by means of the fine hair-like processes with which it is covered. This little fluke (*miracidium*) can only live for a few hours unless it meets with a certain variety of fresh-water snail in which it is to undergo further development. A particular Australian snail in which this development commonly occurs will be described later. Having found its snail, the fluke bores its way into it and then passes to the internal organs, where it commences a complicated course of development. After some months, growth within the snail is completed, and from each original young fluke (*miracidium*) which entered the snail more than a hundred new individuals may have been formed. These new young flukes are still of little more than microscopic size, but are heart-shaped

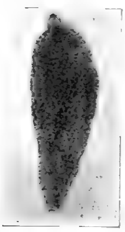

FIG. 1.
The Adult Liver Fluke.
Fasciola hepatica.
(Natural size.)
The presence of this worm in the liver causes fluke disease.

with long tails. They now make their way out of the snails and swim about in the water for a short time, and then attach themselves to blades of grass or weeds. Their tails drop off, and a secretion is thrown out which forms a protective covering or cyst wall around them. These young encysted fluke (*cercariæ*) are the final stage passed outside the sheep, and they are now ready to infest sheep. How is this brought about ? Simply by sheep (or other stock) swallowing the young fluke, while grazing over marshy areas

FIG. 2.

A—Young fluke (*miracidium*) at the time of hatching of the fluke egg. This young fluke swims about in the water until it finds certain fresh water snails in which it must undergo development. Unless it finds these snails it dies in a few hours.

B—Young fluke (*cercaria*) on completing development within the snail. After leaving the body of the snail the fluke swims about for a short period and then attaches to blades of grass growing in the water. Sheep can only contract fluke disease by swallowing young fluke which have undergone development within the snail.

Both greatly enlarged.

or on weeds growing at the side of streams and creeks. Some young fluke, instead of attaching to grass, may float, surrounded by their protective coat, on the surface of the water, and though this is a much less important method of infestation, stock may become infested in this way as they drink from snail-infested pools. *It is only by swallowing the young fluke which have left the snails and have attached to grass or are floating on the water that sheep become infested with fluke.* Having been swallowed, the protective coat surrounding the fluke is dissolved by the digestive juices and the fluke bores its way into the wall of the bowel. Passing through the bowel it falls into the abdominal cavity. Here it wanders about for some days growing in size till it is about an eighth of an inch long, and resembles the adult fluke in shape. At the end of this period it makes its way to the liver, bores into the surface of the organ, and then passes to the bile ducts. Here it becomes mature, and produces eggs eight weeks later.

It is especially important to remember in connexion with the above life-cycle that—

(i) Fluke eggs can develop and hatch only in water.
(ii) The young fluke die unless they find certain fresh-water snails.
(iii) Stock become infested only by grazing on herbage to which fluke have attached themselves after passing out of the snail; or by drinking water on which the young fluke are floating.

Thus it will be seen that the two all-important factors in the spread of fluke disease are water and snails, and without these the disease cannot continue.

4. How and Where Fluke Disease is Spread.

We have seen that snails are necessary for fluke development, but not all snails will serve this purpose. It is desirable that the dangerous varieties should be recognized. The common fresh-water snails met with in Australia are of two types, which may be distinguished as follows. Place the snails with the opening of the shell downwards, and with the point of the shell towards you. It will be seen that in one type the basal coil of the snail when traced downwards curves to the right, in the other to the left. Those snails in which the curve is to the right belong to the dangerous group. The

Fig. 3.—Common Fresh Water Snails. (*Natural size.*)

A—Fluke snails (*Limnea brazieri*). These may be distinguished by the fact that when placed face downwards on the palm of the hand with the point of the shell towards the observer the final coil of the shell curves to the right. Young fluke must undergo development within these snails, so that without them fluke disease could not occur.

B—Snails not known to be carriers of fluke. The final coil of the shell curves to the left.

tentacles of these also will be found to be triangular in shape instead of having the long and slender form of the others. Only one species of snail* has as yet definitely been proved to be a carrier of fluke in Australia, and this is usually small, being up to about ¼ inch in length. It may vary in colour from dull yellowish-brown to a dark brownish-green. Though stock-owners may never have noticed it on their properties, either this snail or one of the same type will certainly be present if losses from fluke continue to occur, and such snails should be sought for in paddocks known to be dangerous. It is quite easy for them to escape detection in heavily weeded creeks or marshes, unless a careful search is made. This variety of snail breeds actively twice a year, the first period being in the late winter and spring (July, August, and September), and the second in the summer (December, January, and February). Some eggs, however, may be found at almost any time in the year. The eggs are laid in cucumber-shaped masses of jelly which may be ½ inch long, and contain from 30 to 40 eggs.

Distribution of Fluke Snails.—The snails are widely distributed and may occur in a variety of situations. They are perhaps most commonly found in shallow marshy areas, such as those spreading out from springs and along the beds of slow-running streams. They may also be found in the spring itself, and in shallow rocky pools, and even in clear running streams or fast flowing rivers. The snails occasionally exist in areas where losses from fluke

* *Limnea brazieri* (Smith).

are unknown, as, for example, in the bore drains or the dry north-western plains of New South Wales. Both the dangerous and the unimportant varieties of snail frequently occupy the same situations, but the latter are perhaps most frequent in the larger pools and small lakes.

It is in certain definite situations that the presence of the fluke snail is most dangerous, and these are those marshy areas which, while containing sufficient water for snail life, are yet so shallow that sheep are able to graze over them. It will be seen that young fluke leaving snails in these situations are easily able to attach themselves to grass, &c., from which position they can readily infest sheep. On any property where losses from fluke are met with, the owner will almost certainly be able to recognize some spot having these characteristics and probably will have associated it with fluke. Where snails occur in clear streams with well defined banks, or in the deeper pools the banks of which are free from weeds or grass, the danger is greatly diminished for the following reasons. Firstly, there is much less chance of sheep's dung containing fluke eggs falling into water and of the fluke eggs

Fig. 4.—A Dangerous Fluke Area.

[*Photo by courtesy of the Federal Capital Commission.*]

A slow-running stream here spreads out to form a snail infested marsh. Sheep are able to graze over the whole of this area, so that conditions are highly favorable to the propagation of fluke life, and sheep are constantly exposed to the risk of infestation with fluke.

hatching, so that the danger of snails becoming infested is proportionately less. Secondly, the young fluke emerging from any snails which do become infested are less likely to become attached to weeds or grass eaten by sheep. This will explain why in some cases, though many snails have been noticed in such pools or streams, yet heavy losses in these paddocks have not been experienced, while in other paddocks where snails are hard to find losses have been serious. In one place conditions are unfavorable to the infestation of snails and sheep, in the other everything predisposes towards it. In Fig. 4

is shown a typically dangerous fluky site where a slow-running stream spreads out to form a snail-infested marsh over which sheep constantly graze.

Why losses from fluke fluctuate from year to year.—It will have been noticed that losses from fluke are subject to considerable variation, but that they tend to be worst after one or two abnormally wet years. It will be readily appreciated that in such years the area of marsh and bog land increases, and new springs break out, so that everything conduces to the hatching of fluke eggs and the spread of infected snails. The latter therefore increase in numbers enormously. At the same time with the extension of the marshy areas, there is a correspondingly greater risk of sheep picking up the young fluke. For this reason, the presence of snails on a property where losses from fluke in normal years are but trivial must be regarded as a source of danger, since one or two years favorable to fluke and snail life may result in serious outbreaks of fluke disease. Cases of this sort have occurred where districts normally hot and dry suffered very serious losses, as in parts of north-western New South Wales, though subsequently the disease has died out on the return to normal conditions.

Though in general wet years are responsible for the heaviest losses from fluke, yet in those parts where losses are fairly constant, dry weather may to some extent predispose towards infestation in certain paddocks. This is due to the fact that in long periods of dry weather, perhaps the only green area in a paddock will be found surrounding a spring or along the course of a stream which almost certainly contains snails. In such a paddock, all the sheep will often be found congregated along this green area, and as long as it remains damp and marshy the chances of sheep becoming infected will be very great, since they are thus forced into the very place where infected snails and, therefore, young fluke are most concentrated. In this fact will be found the reason why in some paddocks, even in dry years, losses from fluke may be serious. At the same time long periods of dryness are unfavorable to the spread of the fluke disease, and it will often die out completely in a district at such times.

It has been said that where snails occur in clear streams or rivers, the chance of their being dangerous to stock is greatly lessened; but they must not on that account be disregarded, since it is possible for them to migrate from these situations up side streams and creeks, till they arrive in situations where their presence is a direct menace. They may also be carried by flood waters over the banks of the river and be deposited in marshy areas at the sides. Another method of spread of fluke disease which must be guarded against is the carrying of young fluke which are floating on the surface of the water to other situations at considerable distances from the place where they emerged from the snail. In this way it is possible that infection may be carried from one property to another, and cases have occurred of stock being infested in this way by water piped to a trough from a spring some distance away.

At what period of the year do snails and stock become infested with fluke?—It has been found that fluke eggs will not hatch during the winter over the greater part of the country where fluke disease is common. Nevertheless, the eggs passed out during the winter, though they do not hatch, remain alive, and with the coming of the warm weather of spring development proceeds, large numbers then hatch within a short time, and infestation of snails results. This latter infestation proceeds probably through the summer months. Spring is therefore a specially important time from the point of view of infestation of snails, and this point will be referred to when dealing with preventive measures. Infestation of sheep will commence at the time when those fluke which have infested snails in the spring have completed development within them, have emerged, and have become attached to grass or weeds. This probably does not occur to a large extent before the late summer months, and then continues to a lesser degree through the autumn and possibly the winter. Late summer and autumn, therefore, are the most dangerous periods for infestation of sheep, though the results of this infestation are frequently only noticed in the subsequent winter.

5. The Two Forms of Fluke Disease—(a) Acute. (b) Chronic.

Two forms of fluke disease occur in Australia, though farmers, for the most part, have recognized only one. These two forms may be described as acute and chronic fluke disease.

(i) *Acute Fluke Disease.*

In describing the life-cycle of the fluke parasite, it was shown that after the sheep had eaten blades of grass to which fluke embryos were attached, these latter after being set free in the bowel, passed through the bowel wall, and fell into the abdominal cavity, and finally after wandering about for some days, made their way to the liver into the surface of which they bored. In the last-named operation a considerable amount of damage to the liver tissue is produced, and through the wounds thus caused there is an escape of blood so that the animals bleed internally into the abdominal cavity. It can easily be imagined that when a large number of fluke are piercing the liver at one time, as for example when a sheep has grazed over a marsh heavily infected with young fluke, the loss of blood and the liver injury may be so great that the sheep may die suddenly without showing any marked signs of ill-health. In the great majority of cases, losses from acute fluke disease have usually been attributed by farmers to other causes, as for example "black disease" in the Monaro district of New South Wales, or the braxy like diseases of Victoria and Tasmania. Losses from acute fluke disease are usually seen during the late summer or early autumn months of February and March, because, as we have seen, it is at this time that young fluke emerge in large numbers from snails. If sheep are attacked by only a few fluke at one time, the liver damage and loss of blood are but slight and the great majority of sheep so attacked show no noticeable signs of ill-health. The fluke then pass to the bile ducts, where they grow to maturity during the winter months and give rise to the chronic form of the disease.

How acute fluke disease may be recognized.—If the carcass of a sheep which has died of acute fluke disease be opened, it will be found that the abdominal cavity contains a quantity of blood-stained or straw-coloured liquid, this being due to the blood which has escaped from the damaged liver. The liver itself may be softened and black in colour, or the surface may be rough and mottled in appearance. It may not be possible to see the young flukes, but if the surface of the liver is carefully examined, they may usually be found as small pinkish objects up to an eighth of an inch in length. It is very desirable that stock-owners should be on the lookout for the acute form of fluke disease, and should not attribute losses from this cause to other factors, thus overlooking the measures necessary for its prevention.

(ii) *Chronic Fluke Disease.*

This is the form of the disease which was previously the only one recognized in most cases as being caused by fluke. After the fluke have made their way into the liver and have become mature, their presence in the bile ducts leads to considerable irritation, damming back of bile, and great resulting thickening of the ducts. In old cases these ducts stand out on the liver as white bands

Fig. 5.—Liver of Sheep affected with Chronic Fluke Disease.

Note how the bile ducts stand out on the normal liver tissue. On opening one of these ducts numerous adult fluke would be found, while the bile would be swarming with eggs. Medicinal treatment will greatly assist sheep suffering from this form of fluke disease.

giving the appearance known as "pipey liver." All these changes in the liver lead to derangement of digestion, while owing to the fact that the fluke sucks blood, there is a continual drain on the body, so that the tissues become pale and anæmic. We have seen that infection of sheep usually commences in large numbers in the late summer months, and that it takes over two months for the fluke to become mature. It follows, therefore, that most sheep will not commence to show marked symptoms of chronic fluke disease till the early winter months, and these will gradually become more serious as the winter progresses.

Symptoms of chronic fluke disease.—Some time after infestation has taken place, sheep will be noticed to be languid and easily fatigued if driven. When caught and examined the membranes of the eye and mouth will be seen to be pale and anæmic. As the disease progresses, the gait of the sheep becomes stiff, the loss of condition grows more marked, and dropsical swellings may develop under the jaws and the abdomen. The animal may live for two or three months and may finally succumb, especially if subjected to unusual exertion or very cold weather. If the animals survive till the spring they tend to throw off the disease and gradually recover. The loss of condition and disturbance of growth, however, is often serious, even in those cases which do not die of the disease. On examining a sheep dying of chronic fluke disease, the body will be found to be wasted and emaciated, while there is sometimes dropsical fluid in the abdomen. In old cases the liver is much altered, the bile ducts stand out prominently, and on opening these large numbers of fluke will be found. Once fluke are present in the liver they may live for over a year, and their effects be felt by the sheep throughout this period.

The ill effects caused by stomach worms may resemble those caused by fluke, and the harmful effects of either of these parasites may be increased by the presence of the other. Wherever fluke is suspected, measures for its treatment should be carried out, and these will at the same time be found to have a beneficial effect on stomach worm infestation should this also be present. As far as possible, however, steps should be taken to ascertain which of the two—fluke or stomach worm—is the primary cause of disease, since if the trouble is due to a stomach worm, it will be advisable to give treatment other than that prescribed for fluke.

Having arrived at a clear understanding of the life-cycle of the liver fluke, and of its relationship to the factors on which infestation of sheep with this parasite depend, it is now possible to consider measures necessary for the control of fluke disease. Control may be attempted in two ways—either (i) by treating sheep to kill the adult parasite in the liver or (ii) by preventive measures designed to prevent infestation of young clean animals and the further infestation of sheep once they have been freed from fluke.

6. The Treatment of Fluke Disease.

In treating sheep for liver fluke, it has been found that most of the drugs usually employed against other internal parasites of sheep, such as the stomach worm, are quite ineffective. One drug, however, has recently been found to surpass all others in efficiency against fluke. This drug—carbon tetrachloride—is a heavy colourless liquid, having a characteristic aromatic odour.

In its properties it is related to chloroform, and if inhaled it has a similar anæsthetic action. It may be conveniently administered and its cost is relatively small.

Dose of carbon tetrachloride.—The dose of carbon tetrachloride which has been found completely effective against fluke is very small, being only 1 cubic centimetre, or in other words about 16 drops. This quantity may be given with safety since it has been found that some sheep will tolerate a dose 30 times as large. There is, however, no good purpose served in increasing the dose, and in some cases there may be a small degree of danger if this be done. Owing to the smallness of the dose, it is necessary to give the drug in such a way that none of it is lost.

Methods of administering the drug.—(i) *In solution, by means of a syringe.* By this method carbon tetrachloride is first diluted to form a larger dose with some suitable substance, and is then given by the mouth by means of a syringe. The most suitable substance for mixing with carbon tetrachloride is liquid paraffin—a colourless oily liquid with which it readily mixes to form a mobile fluid which may be easily given. Four parts of liquid paraffin should be mixed with one part of carbon tetrachloride. The dose of carbon tetrachloride is 1 cubic centimetre (16 drops), so that this must be mixed with 4 cubic centimetres of liquid paraffin to form a total dose of 5 cubic centimetres. It is useless to try and dilute the drug with water since the two will not mix, while the practice of mixing it with kerosene is to be condemned since it may be dangerous to sheep. The dose can be administered by using an ordinary hypodermic syringe (without the needle and of 5 c.c. size), which when filled will contain the correct amount. Certain commercial firms prepare a mixture of the two ingredients in the proper proportions ready to administer, and supply special syringes made to hold the required dose. If the mixture is prepared by the sheep owner, he should take care to secure only chemically pure carbon tetrachloride from reliable wholesale chemists, and the drug should be mixed only with liquid paraffin as above described.

To estimate how much of the drug will be required to treat a flock, 1 quart of carbon tetrachloride and 4 quarts of liquid paraffin should be allowed for every 1,000 sheep to be treated. No more of the mixture should be prepared at one time than is sufficient to treat the required number of sheep, the two ingredients being thoroughly mixed. If not used at once, the mixture should be kept in a well-corked bottle, since the tetrachloride is very volatile and a considerable quantity may be lost by evaporation if it is exposed to the air. When ordering the ready-mixed preparation from wholesale chemists, the purpose for which it is required and the number of sheep to be treated should be stated, and sufficient of the mixture for this number ordered. The container should only be opened when the contents are about to be used.

How to administer carbon tetrachloride in solution.—Pour a small quantity of the mixture into a wide-mouthed container in which the hypodermic syringe (without the needle) can be inserted easily. In order to lessen the evaporation of the carbon tetrachloride one should avoid pouring out large quantities of the mixture at one time. Two catchers should bring the sheep to the operator, who stands on the off side of the head, opens the mouth by placing the left hand over the muzzle and inserting the fingers in the mouth on the near side, while raising the head slightly. The syringe, which is held in the right hand, is then introduced over the tongue, pointed backwards and emptied. (Fig. 6.)

FIG. 6.—Dosing Sheep with Carbon Tetrachloride in Solution.

The drug is first diluted with liquid paraffin to form a larger dose, and is then given by a syringe. Note that the sheep is dosed standing, and that the head must not be forced back. The lower jaw should not be held, as otherwise there is a danger of the drug getting into the windpipe.

(ii) *Giving carbon tetrachloride in capsules.*—Carbon tetrachloride may also be conveniently given in small gelatine containers or capsules. These are of two kinds, viz., (*a*) soft elastic capsules, and (*b*) hard gelatine capsules.

(*a*) Soft elastic capsules ready filled with the required dose (1 c.c.) of carbon tetrachloride are prepared by certain firms. By giving the drug in this way there is no danger of evaporation or leakage, and the correct dosage is guaranteed.

(*b*) Hard gelatine capsules are supplied empty and must be filled before use. When ordering these capsules ask for empty gelatine capsules of the size to hold 1 cubic centimetre. No measuring of the drug is then necessary, the bottom half of the capsules when filled containing the proper dose. Capsules should be filled shortly before use, and this is best done by two assistants holding, opening, and closing the capsules as they are filled by a third person. The drug can be run into the capsules conveniently and quickly with little waste, by using an ordinary fountain pen filler, or a piece of glass tubing drawn out to a point at one end, from which the flow is controlled by means of a finger placed over the other end. The cap of the capsule should be securely put on, since otherwise there is danger of leakage and loss by evaporation.

When ordering capsules ready filled, an equal number to that of sheep to be treated should be ordered, plus 5 per cent. for wastage. If filling the hard capsules 1 quart of carbon tetrachloride should be ordered for every 1,000 sheep, and a sufficient number of the empty capsules.

Administering capsules.—Capsules are best given by means of a small balling gun, which can readily be made by taking a piece of stiff rubber tubing of approximately 9 inches in length and with an internal diameter of $\frac{1}{2}$ inch. A plunger of cane or wood should be smoothed down so that it runs easily in the barrel, and should be sufficiently long to form a handle. In order to avoid the danger of injury to the sheep's throat a guard should be placed on the handle so that when the plunger is driven home the end is not less than $\frac{1}{8}$ inch from the end of the tubing. The end of the plunger should be rounded and smooth so that it will not break the capsules. (Fig. 7.) The operator stands in front of the head, the catcher opens the mouth by grasping both

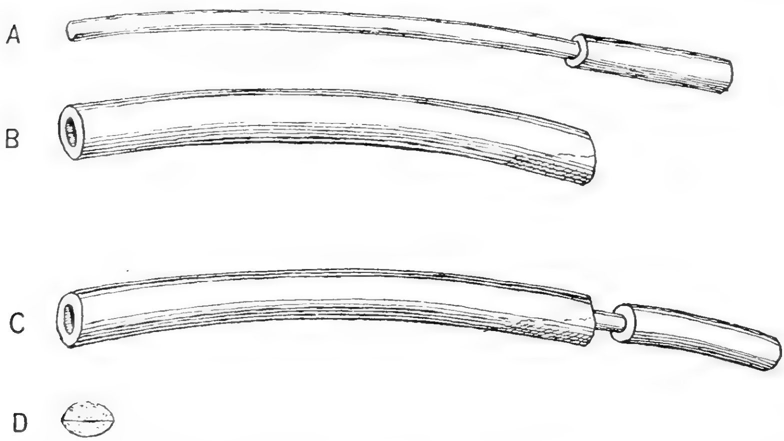

FIG. 7.—Balling Gun for administering Carbon Tetrachloride in Capsules.
A—Plunger. B—Barrel. C—Ready to load. D—Soft gelatine capsule.

Note the guard on the handle, so that the plunger will not project beyond the end of the barrel, and so injure the sheep's throat. The end of the plunger should be round and smooth so as not to break the capsules.

upper and lower jaws, and the barrel is inserted and pushed backwards over the base of the tongue, but not hard against the back of the throat. The plunger is then driven home smartly but not too vigorously, and the gun immediately withdrawn as the holder simultaneously releases the jaws. In this way the sheep swallows the capsule automatically. The administration of capsules by this means is quick and easy; by other methods, such as the use of forceps, it is often uncertain and tedious.

Cost of treatment.—The cost of treatment with carbon tetrachloride varies somewhat according to the method used. If the drug is mixed with liquid paraffin by the stock-owner himself, the cost, allowing for carbon tetrachloride at 3s. per lb. and liquid paraffin at 10s. per gallon, is about ¼d. per sheep. If the mixture is bought ready prepared the cost is approximately ½d. per sheep. If hard gelatine capsules are used and filled by the stock-owner, the cost for material is again about ¼d. per sheep, while if soft elastic ready-filled capsules are used, the cost is approximately 1d. per sheep. After a little experience with the balling gun, capsules may be given almost as quickly as the solution, and by either method one operator, with two men catching, can dose up to 2,000 sheep per day. It has been found that there is no marked variation in the efficacy of the drug whether it be given in capsules or in solution. Usually, stock-owners will be found to keep to the first method of administration of which they have had satisfactory experience. Both methods have their advantages and disadvantages. By giving capsules, there is always the possibility that an occasional sheep may not swallow the capsule and so escape treatment, while in using the hard gelatine capsules, though the gelatine will not be dissolved by its contents for many weeks, there is often leakage from under the cap. In giving the drug in solution, and especially where sheep are roughly and carelessly handled, there is some risk of the head being forced too far back, and some of the solution getting into the windpipe; also unless the mixture is carefully bottled and protected from evaporation, a considerable proportion of the carbon tetrachloride may be lost.

Precautions to be observed in dosing with carbon tetrachloride.—Sheep should be dosed standing. The head should be slightly raised but not forced backwards, otherwise difficulty in swallowing will cause danger from inhalation. In giving the drug in solution, the bottom jaw should never be tightly held so that the sheep is prevented from swallowing easily when the dose is delivered. Do not give more than the dose of 1 c.c (16 drops) since larger doses will not increase the efficacy of the drug and may cause ill effects. It is not necessary to withhold food or water before or after dosing, but sheep are usually yarded overnight and treated in the morning. It is advisable, however, where sheep have been hand-fed on concentrates such as linseed nuts, to withhold these for one week before dosing.

When to treat with carbon tetrachloride.—Owing to the seasonal escape of young fluke from the snail, sheep pick up their heaviest infestation in the late summer and autumn months, though they may continue to pick up some fluke throughout the winter. It has been found that carbon tetrachloride will not kill the fluke until they have reached the bile ducts, and this does not occur until several weeks after they have entered the sheep. The first treatment should therefore be given in the early winter, as soon as possible after the majority of the fluke picked up in the summer and autumn (January to April) have reached the bile ducts, that is, about the middle of May. Owing to the fact that some of the small fluke already in the sheep may not be killed by a single treatment, it is advisable, in districts where infestation is usually heavy, to give a second treatment about the beginning of July. Where it is not practicable to give two treatments the first should be given a little later, about the first week in June. The necessity for giving two treatments will be largely determined by the effects of the first. Should the sheep a month or six weeks later show little sign of improvement in condition and still exhibit symptoms of fluke disease, a second treatment is advisable.

Sheep in advanced stages of liver rot may be treated without danger other than that due to handling, and will usually commence to show a marked improvement in condition within a few days. Ewes in lamb should not be treated within three weeks prior to lambing owing to the danger from handling; otherwise dosing with carbon tetrachloride either before or after lambing does not appear to be harmful to the lambs.

Reports of mortality in sheep after dosing with carbon tetrachloride are made from time to time, but it is seldom that such mortality can be directly attributed to its use. In many cases the mortality has commenced before dosing, in others it has been due to other causes, while in some instances the purity of the drug used has been questionable. In any case where sheep are badly affected with fluke, the benefits accruing from the treatment are such as greatly to outweigh all reasonable objections, and to justify taking the risk of any slight mortality which might occur.

7. The Prevention of Fluke Disease.

Though medicinal treatment for fluke is very useful in improving the condition of the flock and saving many sheep which would otherwise die of fluke disease, it must be remembered that alone it will never effect the total eradication of fluke, and it is therefore *not* the most desirable method of controlling the disease. Moreover, it will not save a large number of sheep which die of acute fluke disease at the time the young fluke enter the liver, nor will it prevent re-infestation. It is therefore all-important that other measures should be adopted by which the disease may be eradicated for all time, rather than merely to lessen losses from year to year.

In considering the life-cycle of the parasite it was seen that two things were necessary for its survival—(i) marshy or boggy areas over which sheep can graze and in which the fluke eggs will hatch, and (ii) certain fresh-water snails in which the fluke must develop. It was further shown that these dangerous conditions existed particularly in the vicinity of springs and bogs, or along the course of slow-running marshy streams. Preventive measures must therefore aim at treating these dangerous sites so that the area of marsh and bog is reduced to a minimum, and at the destruction of all fresh-water snails present in these places. The first of these aims can be achieved very largely by proper drainage, while the second is now made possible by the use of chemicals.

Drainage of marsh land.—Where practicable, all marshy areas should be efficiently drained. In the case of springs, a channel should be dug to carry water away so that it no longer spreads out to form a bog, but is drained straight down to the nearest natural channel, which should also be cleared of weeds and deepened. In the case of clear springs which are of value for watering purposes, these may be rendered safe by bricking or concreting the sides and then piping the water off to troughs from which stock are watered. Where this is done, precautions must be taken to see that the overflow from the trough does not again lead to new bog formation which would soon become a breeding centre for snails. It is not uncommon to find both troughs and the bog surrounding them to contain numerous snails. Owing to the danger that exists of any young fluke which are floating on the surface of water being carried a considerable distance, it is necessary before piping off water from springs first to treat the spring so that all snails in it are killed.

Slow-running streams with swampy backwaters should have their central channel deepened, the sides cut clean and *freed from all grass and weeds.* Other extensive areas of boggy land should be drained by digging lateral drains opening herringbone fashion into a central channel which leads down to some safe watercourse. By these means the greater part of the dangerous areas dry up and the majority of the snails die, while those remaining alive are forced into the cleared channels. It will be seen that, by proper drainage, the risk of sheep becoming infested is greatly reduced, since not only is the number of snails greatly diminished but also those surviving are no longer able to exist in those sites over which sheep can graze, while any young fluke escaping from the snails in the cleared watercourses are much less likely to become attached where they will be eaten by sheep or cattle. In addition the treating of the watercourses to kill the surviving snails is greatly facilitated.

Fencing not advisable.—The practice of fencing off fluky places so as to prevent stock being exposed to infection is seldom advisable, since it often involves considerable expense, causes in some cases the loss of considerable grazing areas, and often creates serious difficulty in watering. Fencing of small areas such as the bog surrounding a spring often results in an overgrowth of weeds and the blockage of all drainage so that by the gradual extension of the original area the fence ultimately becomes uselsss.

In addition to drainage or instead of it, where owing to the nature of the area involved and labour difficulties, drainage is not practicable, the destruction of snails may be brought about by the use of chemicals.

The use of bluestone.—The most suitable chemical to use for this purpose is copper sulphate or "bluestone," which, when present in very minute quantities in water, is rapidly fatal to all snails. The aim in the use of "bluestone" is to form a weak solution of this chemical in all the water of the areas in which fluke snails exist. In the case of pools and springs this may be done by first breaking the copper sulphate in small pieces, tieing them in a bag attached to the end of a pole, and then dragging this bag backwards and forwards through the water till the latter acquires a faint blue tinge. In the case of running streams, bags of bluestone may be placed at intervals along the course of the stream so that the chemical is gradually dissolved. While these methods are effective in certain cases, they are quite ineffective in others, as, for example, slow-running streams with stagnant backwaters and in irregular marshy areas. It can be seen that in a shallow, slow-running stream (see Fig. 8), though the bluestone is carried down along the main channel and may kill all the snails there, it often entirely fails to reach the weedy backwaters and disconnected pools at the sides. These are just the places which are most dangerous to sheep, and in a stream so treated they will often be found to contain numerous snails though the stock-owner is confident that he has rendered the area quite safe. Such streams, and all shallow boggy areas, can best be satisfactorily treated by broadcasting bluestone, after grinding the latter to a fine powder and mixing it with sand.

Broadcasting bluestone.—A satisfactory mixture is made by mixing 1 part of bluestone with 4 of sand and then broadcasting by hand at the rate of 30 lb. of bluestone per acre. Thus 30 lb. of bluestone are mixed with 120 lb. of sand, making 150 lb. of the mixture to be applied per acre. Just before use, the bluestone should be freshly ground to a fine uniform powder and then thoroughly mixed with the requisite quantity of sand. Before grinding, it is important to see that the bluestone is in the form of hard blue crystals, and that it is not white and powdery. In estimating the quantity to be used the approximate length and breadth of the area to be treated is taken and number of acres so found. Just a sufficient quantity of bluestone to treat the area in question should be used.

For example, a shallow weedy stream 200 yards long by roughly 4 yards wide is to be treated—

$$200 \times 4 = 800 \text{ square yards.}$$

As there are 4,840 square yards in an acre

$$\frac{800}{4{,}840} = \tfrac{1}{6} \text{ acre.}$$

One-sixth of 30 lb.=5 lb., therefore 5 lb. of bluestone would be required to treat this stream, and should be mixed with 20 lb. of sand, making 25 lb. of the mixture.

Before applying to the whole area, a small section should be measured and sufficient of the mixture weighed out to treat this at the required rate. This small section should then be treated and the experience so gained will prove useful in helping the operator to determine how thickly he must distribute the mixture to cover the whole area evenly.

The cost of this method of treatment is not great. Bluestone may be purchased at approximately 4d. per lb. in cwt. lots (less for larger quantities), and about 2 acres per day can be thoroughly treated by one man. One of the chief labour items is that entailed in powdering the bluestone before use. This is best done by first breaking up the big pieces with a large hammer

FIG. 8. —Where to Broadcast Bluestone.

[*Photo by courtesy of the Federal Capital Commission.*

Slow-running stream showing disconnected pools and damp mud at the sides, in which snails were numerous. This type of stream is best treated by broadcasting bluestone as a fine powder mixed with sand. After treating this stream in this way, using 30 lbs. of bluestone per acre, not a single live snail could be found.

until they are of a size to be taken by a small domestic hand crusher. These crushers can be purchased for about 30s., and at least 10 lb. of bluestone can be powdered by them in an hour.

Cost of broadcasting.—The approximate cost of broadcasting bluestone should not be more than 25s. per acre, made up as follows :—

30 lb. of bluestone at 4d. per lb.	£0 10 0
Powdering of bluestone, 30 lb., half-day's labour at 15s. day	0 7 6
Applying bluestone at the rate of 2 acres per day, i.e., half-day's labour	0 7 6
Cost per acre	£1 5 0

In treating streams by this method, care must be taken that the bluestone is spread not only over places actually covered by water, but also those places which though not under water are still moist. It is known that the fluke snails though killed by complete dryness are able to exist for considerable periods in apparently dry places. As the water recedes, the snails make their way into the cracks in the mud, and situations which are apparently dry and free from snails may actually harbour considerable numbers of them in the moist mud below the surface. With the first shower of rain, snails so hidden will emerge. It is therefore necessary when treating a slow-running stream, or marsh, to spread the copper sulphate over a margin beyond the limits of the obviously wet areas.

It is not sufficient to broadcast only here and there along a creek, since the action of the " bluestone " will not extend for more than a very short distance above or below the area actually covered. Less than 50 yards below a thoroughly treated stretch of water snails may be found in large numbers. It is therefore necessary to broadcast along the entire length of the creek if it is to be rendered safe. Where deep pools occur in a marshy stream or bog, these, in addition to broadcasting, should receive special treatment by means of bluestone tied in a bag, and where the central channel of a stream is deep and the water swift flowing, deposits of bluestone should also be placed at intervals along its course.

When broadcasting over the bed of a stream, care should be taken to observe and treat any springs or seepage patches which sometimes arise on the banks several feet above. Snails may be numerous in these places and from them reinfestation of a treated stream may take place. Though the use of bluestone will rapidly prove fatal to snails, it does not affect vegetation nor has it been found to cause any ill effects to stock. In order, however, *to avoid all risks of poisoning through stock grazing over freshly treated areas* animals should be kept off these for one week, or preferably until a shower of rain has fallen. It should be remembered also that the use of bluestone in the manner prescribed will kill fish.

When to broadcast bluestone.—Broadcasting of bluestone at any period of the year will confer a great measure of protection on stock, but there are certain periods when it is especially desirable to do this so as to lessen the immediate danger. Owing to the fact that the principal escape of young fluke (*cercariae*) from the snail takes place during the late summer and autumn months, every effort should be made to carry out the first treatment on all properties where losses from fluke occur *before the end of December*. If this is done thoroughly, the great majority of snails will be killed before the young fluke are ready to leave them. Sheep are thus protected from the following seasonal infestation. Where it is not possible to adopt preventive measures in December they should be carried out as soon as possible in the new year. A fortnight after treatment, all the areas should be thoroughly examined and if live snails are still present these places should be retreated at once. In sites where snails were numerous previously, it should now be possible to find the empty shells of the snails killed by the treatment.

Unfortunately it is known that snail eggs are not destroyed by bluestone, and these may hatch after treatment and lead to reinfestation. During the summer the snails breed actively, and in December and January egg masses are very numerous. Large numbers of young snails may thus emerge after a treatment which completely destroyed all the adults. It is necessary, therefore, to give a second treatment to all fluky areas at such a time when all eggs from the summer breeding season have hatched, and before the next egg-laying period begins in July. This second treatment should therefore be given before the end of June. Carrying out treatment at this time also ensures that all snails will be destroyed before fluke eggs, which have passed out of sheep in the winter, commence to hatch in the first warm weather of spring. The young fluke (miracidia) being unable to find a snail, cannot survive. Where preventive measures are *first* carried out in June, the *second* treatment should be given in December. Some stock-owners think that having once treated areas with bluestone its action will continue over a long period, rendering a second treatment unnecessary. This is not the case, and the bluestone on the pastures probably does not remain poisonous to snails for more than one week. *It is preferable to broadcast just before rain falls or while light rain is falling.* In this way the bluestone is washed off the grass and herbage to where it will reach the snails, while any risk of poisoning of stock is simultaneously eliminated. Doubt is sometimes expressed as to whether treatment carried out in winter will prove effective, since it is thought that at this time snails may be hibernating in the mud where they will not be affected by the bluestone. So far from this happening, snails may be found alive and active in the coldest winter weather and may be seen moving about rapidly in ice-covered pools.

Dangers of reinfestation.—When "fluky" paddocks have been rendered safe by thorough preventive measures, care must be taken that they do not again become infested. This may easily occur where a stream runs through two adjoining properties in one of which treatment is carried out while in the other nothing is done. Snails may travel considerable distances up stream against the current, while they are often carried down stream after heavy rains, and may thus pass from the untreated to the treated property. Stock

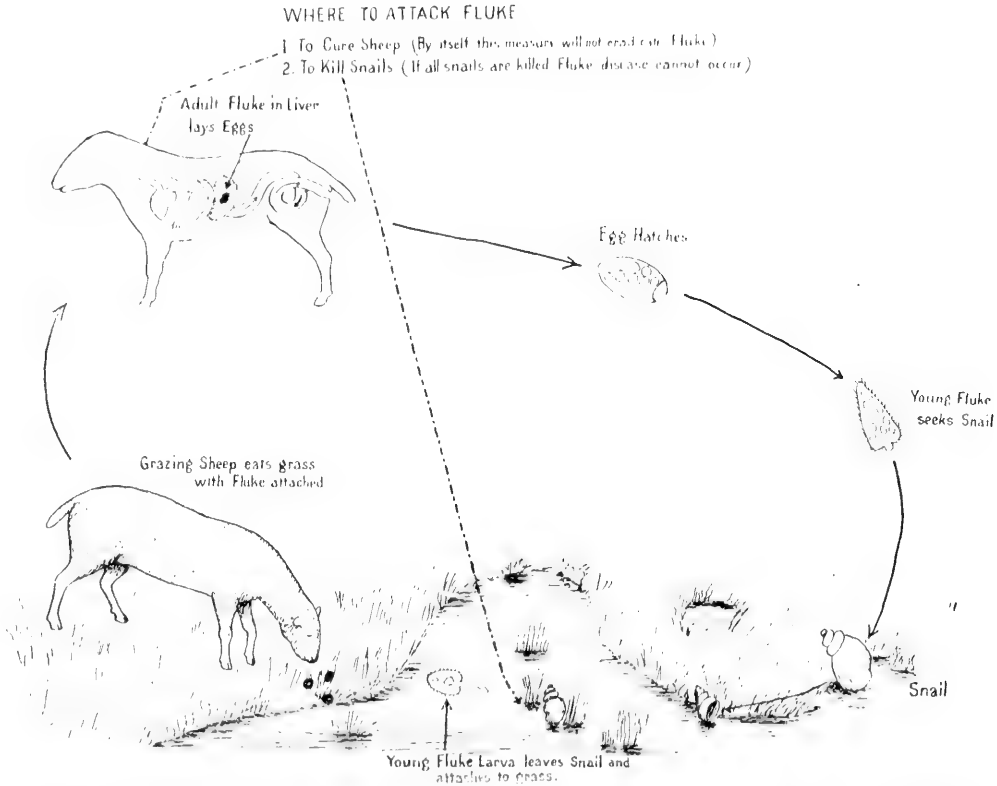

FIG. 9.—Diagram illustrating the life-cycle of the Liver Fluke and showing how fluke disease may be controlled.

owners should therefore co-operate as far as possible in the work of fluke eradication, so that the work of one is not rendered useless by the neglect of the other. It has been said that fluke snails may be found in large streams and even fast flowing rivers, and though their presence in these situations is often not a serious menace to stock, they may eventually make their way up side streams until they arrive in marshy situations where they will be a direct source of danger. Reinfestation of clean properties in these ways must therefore be watched. It should also be remembered that rabbits may be infested with fluke, and the mere keeping of sheep or cattle out of a paddock where snails are allowed to remain will not necessarily render it free from infestation by the parasite. In all paddocks therefore destruction of all snails must be aimed at.

Fluke disease is preventible.—It is hoped that it has been made clear that fluke disease in the great majority of cases is *preventible*, without excessive expenditure of labour or money. That losses from this cause should be allowed to continue, when the means for prevention are in the stock-owners' hands, is unthinkable.

ACT NOW.—After one or two wet years your present slight losses from fluke disease may become disastrous, while prompt action now will result in immediate benefit.

SUMMARY.

I. Fluke Disease is caused by a leaf-like parasite in the liver. See page 3.

II. The eggs of the fluke can hatch only in water, and the young fluke must pass through certain snails before they infect sheep. See page 4.

III. Fluke may cause either acute or chronic fluke disease. Acute fluke disease is often mistaken by stock-owners for other diseases. See page 9.

IV. Sheep suffering from chronic fluke disease may be freed from fluke by dosing them with carbon tetrachloride. See page 11.

V. Fluke disease may be eradicated completely by—

(i) Draining "fluky" areas (see page 16).

and

(ii) Snail destruction (see page 17).

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PAMPHLET No. 6.

COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

STANDARD METHODS OF DRYING SULTANA GRAPES IN AUSTRALIA.

By
A. V. LYON, M.Agr.Sc.

MELBOURNE, 1928

By Authority:
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PREFACE.

This pamphlet was compiled for the purpose of standardizing the three principal processes used in Australia for drying sultana grapes.

In November, 1927, the producers, packers and market representatives of the dried fruit industry in joint conference unanimously decided that a reduction in the number of types of dried sultanas was essential for successful marketing. They further requested the Council for Scientific and Industrial Research to issue standard recommendations in order to eliminate the many variations which had arisen during the transition period in which two new dips for sultanas were introduced.

This present pamphlet has accordingly been prepared.

Standard Methods of Drying Sultana Grapes in Australia.

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I.—INTRODUCTION.

1. General.—The major portion of the sultanas produced in Australia is grown in the Murray River Valley. The grapes are dried on roofed racks, as the possibilities of summer rains and consequent damage to the fruits are such that full exposure for sun drying is not warranted. Artificial drying is not a common practice, because in the majority of seasons the atmosphere dries the fruit at a rate sufficient to prevent injury and to preserve colour.

In occasional seasons, however, summer rains occur so frequently in the drying period (February and March), that inferior quality results from a retardation of the drying rate and an increase in the moisture content of the exposed fruit. For this reason, it is not possible to obtain proportionate quantities of the various grades from year to year, the best quality resulting only during such periods of the drying season as are favorable.

2. General Factors Affecting the Quality of Dried Fruits.—The quality of the resultant dried product is dependent on three chief factors :—

(*a*) The quality of the fresh fruit.
(*b*) The method of processing.
(*c*) The weather during the drying period.

The first of these three factors has been discussed in a previous publication.* Quality is affected by practically all routine field operations and also by uncontrollable circumstances such as climate, weather, soil types, and the previous history of the vineyard. With so many factors operating, it is inevitable that variations in the quality of the fresh fruit will result, and that they will be reflected in the dried product.

As the duration of the drying period extends beyond the period of any reliable weather forecasts which it is possible to make at the time of picking, it is not practicable to vary processing—which is applied mainly to the fresh fruit—according to the weather of the subsequent period during which the grapes are dried. The result is that the choice of method is chiefly determined by the class of fresh fruit available, the climate of the district, and the capacity of the drying plant. The extent to which the choice may justifiably be affected by these conditions will be discussed after the three chief methods of processing have been described.

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* Institute of Science and Industry, Australia, Bull. 28 (1924).

II.—THE BOILING DIP.

1. General.—The boiling caustic dip consists of a solution of caustic soda, at or just under boiling point, in which grapes are immersed prior to their exposure for drying. The dip results in a quicker drying rate, by removing the waxy "bloom" of the grapes and by slightly cracking the berries. It also gives a characteristic brown colour to the fruit, due to the action of the soda on the pigments of the grape.

2. The Dipping Tank.—The boiling dip has been in general use in the Murray River Valley for over thirty years, and many types of suitable tanks have been evolved. The requirements are a circulatory system, in which hollow iron tubes, through which the water passes, are used as fire bars; and a tank capacity of 75 to 100 gallons, in order that the temperature may be maintained. The tanks are usually bricked in for preservation of heat. Wood is used as fuel, the furnace taking lengths of 3 to 4 feet.

3. Concentration of the Solution.—The solution should be of such a concentration that the waxy bloom of the dipped grape is entirely and easily removed. In the case of the boiling dip, this condition is invariably accompanied by a cracking of the berries.

A concentration of from 0.3 to 0.4 per cent. of caustic soda (3 to 4 lb. per 100 gallons) is the range within which the desired results are obtained in the majority of cases. Variations in the maturity of the fruit and in the quantity of bloom may render it necessary to go outside this range in special circumstances. The removal of the bloom, rather than the cracking of the fruit, should be the guide as to the effectiveness of the dip.

The dipping of fruit of uniform quality presents little difficulty. Persistence of bloom is counteracted by an increase, and over-cracking by a decrease, in the strength of the solution. With uniform quality fruit, the removal of the bloom can be obtained at a concentration which cracks the fruit little or not at all, and in general it is secured at a concentration which does not crack excessively.

With mixed fruit, the problem is more difficult, as under-dipped fruit (on which bloom persists) and over-dipped fruit (excessively cracked) may result from the same treatment. As a matter of policy, underdipping of individual bunches in a mixed sample should always be avoided, as the resultant dark berries reduce the quality of the sample to a greater extent than do the dark-brown cracked berries resulting from over-dipping. Under these circumstances the best results are obtained only by dividing the fruit according to its characteristics, and regulating the dip accordingly. Cases where this is necessary, however, are comparatively rare.

In practice, the concentration range over which satisfactory results are obtained is a somewhat wide one. It is advisable, in the first instance, to prepare a dip at a low concentration ($2\frac{1}{2}$ lb. caustic soda per 100 gallons water) and to increase the concentration by $\frac{1}{2}$ lb. additions until results are satisfactory.

4. Alterations in the Concentration of the Dip. During use the solution in the dip tank decreases in volume as the result of evaporation and removal of the quantity that adheres to the bunches. In addition the caustic soda is slowly neutralized by the acids of the fruit. The net result is a slight increase of concentration and a considerable diminution of total volume. Additions to the dip should thus be relatively weaker than the solution in use. They are conveniently made by adding water until the original volume is restored and caustic soda at the rate of approximately 1 lb. for every 300 " buckets " of fruit that have passed through the solution. The ultimate guide for strength, as in the first instance, is the condition of the dipped fruit. Additions of caustic soda to a heated dip should be made carefully and in small quantities.

5. Dipping the Fruit.—The fruit is usually picked direct into perforated tins, which allow quick draining. These tins hold 14 to 16 lb of fruit. Overfilling must be avoided, as it results in crushing the upper bunches during cartage and in a less uniform wetting and period of immersion in the dip.

A quick immersion (1½ to 2 seconds) is sufficient, the tin of fruit usually being passed through the solution, from right to left in a circular line. This ensures greater uniformity, that portion of the fruit which first enters the solution being also the first to leave it.

III.—THE MODIFIED TEMPERATURE CAUSTIC DIP.

1. General.—This dip is prepared and used in a similar way to the boiling dip. The essential difference is that it is used at a lower temperature (190°–196° F.). As a result the browning due to the action of the caustic soda solution is less intense, and a slightly higher concentration is required to remove the bloom satisfactorily.

2. The Dip Tank.—All types of tank suitable for the boiling dip have been successfully used for the modified temperature dip.

3. The Temperature.—Alteration of temperature is a frequent cause of variation in colour of the resultant dried fruit. The browning effect of the caustic on the grape pigments decreases materially as the temperature is lowered, and the tendency for " bloomy " and subsequently dark berries increases. Temperatures above the range tend to the formation of a dark-brown colour typical of fruit from the boiling dip. Care must therefore be taken to avoid these extremes. In particular, a regulation of the fuel supply according to the rate of working is necessary. In practice it is found convenient to have a prepared cold solution for quick reduction should the temperature become too high and a supply of light wood to maintain the temperature during rush periods. Although more difficult than in the case of the boiling dip—in which the maximum temperature is fixed—it is practicable, with a little experience, to keep the modified temperature dip within the desired range of temperature without unduly influencing the rate of working.

A mercury thermometer, with a wooden frame and extension as a handle, is a necessary part of the equipment. The thermometer should be long enough for the bulb to remain within the solution while the reading is being taken, or alternatively a maximum thermometer should be used.

4. Concentration of the Solution.—The guide for effectiveness of this dip is somewhat similar to that of the boiling dip, excepting that removal of the bloom without perceptible cracking of the berries occurs more frequently. The range of the effective concentration is slightly higher, usually falling between $3\frac{1}{2}$ to $4\frac{1}{2}$ lb. of caustic soda per 100 gallons of water.

The concentration of the solution increases with use, though naturally not to the same extent as in the case of the boiling dip. The net result is that comparatively more caustic soda and less water are necessary for replacement.

5. Dipping the Fruit.—No alteration of the process as described for the boiling dip is required.

IV.—THE COLD DIP.

1. General.—The cold dip is a solution of potassium carbonate, at air temperature, in which an emulsion of olive oil has been incorporated. The grapes immersed in this solution undergo a change, the natural bloom being removed and a thin oily coating substituted.

The process differs from the caustic soda dips previously described in that the solution does not appreciably affect the natural colour due to the pigments of the grape. These pigments, particularly the chlorophyll, must be destroyed by exposure to the sun's rays subsequent to dipping.

2. The Dip Tanks.—Three types of plant are used—

(*a*) The rectangular tank (6 ft. x 3 ft. x $1\frac{1}{2}$ ft. deep), in which 80 to 85 gallons of solution will cover 12 dip tins.

(*b*) Single or double lever systems, by which the group of buckets is immersed and withdrawn on a platform.

(*c*) The wheel system, by which a number of platforms holding the fruit revolve on an axle, and pass through the dipping solution in turn.

All the above types have proved satisfactory, though a disadvantage of (*a*) is that the hands of the operator need to be immersed in the solution and any small abrasion may become a painful sore.

3. Concentration of the Potassium Carbonate Solution.—A solution containing approximately 5 per cent. of potassium carbonate (1 lb. to 2 gallons of water) gives the best results. Excessive concentration results in discoloration at the ends of the berries, while a weak solution increases the proportion of "bluish" berries tending to the colour of undipped fruit. The solution is usually prepared in the dip tank.

4. Preparation of an Emulson of Olive Oil.—Olive oil readily emulsifies in a solution of potassium carbonate in the cold. Emulsification in a separate vessel is recommended, for the following two reasons :—

(*a*) A solution containing 1 per cent. of potassium carbonate gives a finer emulsion than the 5 per cent. solution used for dipping.

(*b*) By withdrawing the emulsion from a tap at the bottom, it is easy to discard the un-emulsified (floating) substances which appear under certain conditions. The emulsion, if left standing, separates into layers. For this reason it should be stirred, and left for one minute to allow floating substances to rise, before being withdrawn.

The emulsion may be conveniently prepared in a kerosene tin, to which a tap has been fitted near the bottom. With the exception of the oil, quantities may then be measured in terms of the depth of the solution, as under :—

(*a*) Pour 2 inches of the 5 per cent. solution of potassium carbonate into the tin.

(*b*) Add water to a depth of approximately 10 inches.

(*c*) Add three pints of olive oil and stir rapidly.

(*d*) Make up to a depth of 12 inches with water

Four inches of this emulsion then represents one pint of olive oil.

5. Quantity of Olive Oil in the Dip.—The emulsion is run directly into the 5 per cent. solution of potassium carbonate previously prepared in the dip tank. It is necessary that sufficient should be added to coat the fruit completely after an immersion of four minutes. The quantity required varies with different classes of fruit and with the quality of the emulsion. The ultimate guide is the appearance of the "fruit," which should show no dry or "bloomy" patches, after being dipped. (The small waxy shot-size dots are excepted.) The minimum amount of oil may be stated at 1½ pints (6 inches of the emulsion previously described) per 50 gallons of solution.

It is well to commence testing at this stage, and to add oil progressively in quantities of a ¼ pint (1 inch), until the berries are coated after a four-minute immersion. This represents the minimum amount of olive oil. An excess, equivalent to half a pint of oil per 50 gallons, should be added before use. This is essential, as proportionately greater quantities of oil than of solution are taken out on the fruit during use of the dip, and it is therefore necessary to work from an excess to the minimum.

6. Additions during Use.—Continued immersions of tins of fruit cause little alteration of the concentration of potassium carbonate in the dip. Such additions as are necessary for replacement of liquid used in wetting the fruit may be made by adding potassium carbonate solution of the same concentration as originally made in the dip.

Filtering through coarse sand is useful for cleaning the dip when suspended soil particles are too much in evidence. The brown coloration due to substances dissolved from the grapes appears to do no harm. In practice, a dipping solution with two or three filterings and additions at full strength, may be used for three or four thousand tins of fruit before it is necessary to discard it on account of stickiness from the dissolved sugar of the grapes. The soluble salts dissolved from earthy substances on the fruit and tins serve as a drying agent, and are not a matter for concern.

Additions of olive oil emulsion at frequent intervals are essential. The practical rule is to make additions, equivalent to a ½ pint of olive oil per 50 gallons of dip solution, when traceries of bloom begin to appear on the dipped fruit.

7. Period of Immersion in the Dip.—An immersion of the fruit for four minutes in the solution gives the best results. Shorter periods (three, or even two minutes) have been successfully used by increasing the quantity of olive oil, though shortening the period tends to a greater percentage of dark berries on mixed samples of grapes.

All prelimiary trials should be made at the period of immersion at which the dip is to be used.

V.—TREATMENT OF DIPPED FRUIT.

1. General.—The following remarks, except where otherwise indicated, are common to fruit from any one of the three dips previously described. It must be clearly recognized, however, that although correct dipping of the fruit is an essential to quality, any advantage thus gained is completely lost if any damage to the fruit occurs subsequently.

2. Draining.—Thorough draining of all dipped fruit is essential as otherwise the drippings discolour the grapes. Drainings from the cold dip are usually clean and may be returned directly from the draining stand to the dip tank. Hot dip drainings contain more sediment and should be collected in a separate vessel. After settling, the upper liquid may be decanted into the tank, and the sediment discarded. The run-off from the draining stand is the practical guide for completeness of draining. A useful precaution is to remove tins from the draining stand in the same order as that in which they were placed thereon.

3. Spreading.—Thin spreading on the racks is essential for quality, otherwise retardation of drying and deterioration of quality will result on a proportion of the fruit. Overlapping of bunches must be avoided. The use of the "spreading tray" is an aid to quality, as if spreading is done on the netting, laceration of the bunches and an increase in the proportion of fallen berries are inevitable. A little experience will enable the operator to spread direct on to the tray and to withdraw the latter leaving the fruit in its final position. It is preferable to spread the upper tiers first in order that the detached berries shall fall through and not become mixed with fruit previously spread on the lower tiers. In order to attain uniformity of drying weather for each division of the fruit, it is preferable to fill each section or "bay" completely before proceeding to the next one.

4. Shading.—A roofed rack is essential in the majority of seasons. Otherwise wetting and certain deterioration of the fruit results. Uniform shading and consequent uniformity of the dried product are not possible if the upper tier is exposed. The best results are secured by building the rack on a north and south line and roofing with galvanized iron allowing an overlap of $1\frac{1}{2}$ to 2 feet beyond the edge of the netting on which the fruit is placed. This ensures shade for all the fruit during the hottest portions of the day.

Side curtains (hessian) give an advantage in preventing excessive browning, and a disadvantage in reducing the drying rate. On the whole, they are not recommended except to prevent rain beating in, as the deterioration from delayed drying is a more serious matter than is sun browning on the edges.

5. Spraying.—Spraying definitely hastens the drying rate and this preserves quality. It is essential on all cold-dipped fruit, except during exceptionally hot weather in which the drying rate is satisfactory. It is of advantage after the modified dip in normal weather, and essential on all fruit if showery and dull weather sets in. The solution for spraying is similar to that of the cold dip, except that it is not possible to adjust the proportion of oil by trial. The equivalent of $1\frac{1}{2}$ pints of olive oil per 50 gallons gives the best results, though the oil may be increased or diminished within limits of a $\frac{1}{4}$ pint per 50 gallons according to the amount of oil showing on the fruit. In normal weather, the first spray should be applied on the third day of the drying period, and thereafter at intervals of three days.

6. Removal from the Rack.—The fruit should be thoroughly dry before removal from the rack. Disturbance of partially dried fruit results in a very mixed sample, as enzyme and ferment action follow on some of the berries, dulling and darkening them. Bundling in hessian, if the fruit is only partially dry, is never satisfactory, as the darkening becomes general and is seldom uniform.

The practical rule is to remove fruit from the rack only in settled weather and when there is a certainty of further drying on the hessian before handling may become a necessity. The fruit should be so dry that it falls from the rack on shaking the tiers. The use of pitch forks or sticks for removing dried fruit is a very bad practice, and the necessity for such measures indicates that further drying is required.

7. Drying on Hessian.—The degree of dryness usually attained on the rack is not sufficient for boxing. Further exposure of the fruit, thinly spread on hessian, is necessary both for additional drying and for greater uniformity of colour. The experience of recent years has demonstrated that producers can judge the desired moisture content correctly. Nevertheless a continuance of rigid inspection is necessary to ensure compliance with regulations in this respect.

8. Boxing.—Except for the prevention of wetting by rain, bundling in hessian prior to boxing should not be done until evening, when the fruit has become cool.

Prior to boxing, the standard of dryness should be a little more rigid than the standard accepted on delivery. Alteration of the distribution of the moisture, from the interior to the outside of the individual berries, renders this precaution necessary.

9. Final Treatment of Cold Dipped Fruit.—On removal from the rack, cold dipped fruit is more or less unsightly. The green "chlorophyll" colour is preserved to varying degrees on different berries; browning due to "edge" exposure is also in evidence; and a coating of potassium carbonate from the dip and the spray is also a feature.

Correction is secured by direct exposure to the sun's rays, until the green tinge is removed. This may take two to four days according to the weather. Usually, by the time bleaching is completed, the fruit is over dry. For this reason, the final washing for removal of potash and for the moistening of the skin should be performed after bleaching. In practice, plunging the fruit wrapped in hessian into a large tank containing the wash proves cheap and efficient. The rectilinear tanks used for the cold dip are in general use for this purpose. Two or three old porous pieces of hessian are used for washing, the fruit being received on these from dry hessian on which it is replaced after draining.

As soon as practicable after washing, the fruit is exposed to the sun until the desired degree of dryness is secured. In practice the washing is usually done in the forenoon and in ordinary weather the fruit is re-dried by the evening of the same day. Selection of a fine day for washing is always possible, as prior to the operation the fruit is dry and may be "bundled" without damage until favourable weather is experienced.

10. Preparation of the Wash.—The wash in general use consists of a solution containing 0.5 per cent. of potassium carbonate (2½ lb. in 50 gallons) to which 1½ pints of olive oil, emulsified in the usual way, have been added for each 50 gallons of solution. As in the case of the spray, slight variations in the percentage of olive oil are made according to the condition of the fruit.

An increase in concentration results as the potassium carbonate on the fruit dissolves in the wash. This is not a matter for concern, as the wash is discarded for other reasons—chiefly dissolved sugar—before the concentration is sufficient to give a coating of carbonate to the dried product. The appearance of the washed fruit indicates the point at which a used wash should be replaced. In practice approximately 3 tons of dried fruit can be efficiently washed before replacement becomes necessary.

VI.—SPECIAL EQUIPMENT.

1. The Baume Hydrometer.—Hydrometers graduated on the Baumé scale are in common use in Australia, as viticulturists have long been accustomed to interpret maturity of fruit in terms of the Baumé scale. A 5-inch scale, graduated from 0° to 16°, proves satisfactory. This scale is sufficiently wide to measure the density of grape juice, as well as all needed concentrations of potassium carbonate solution.

The standard cold dip solution (1 lb. to 2 gallons water) has a Baumé reading of approximately 5.7°. The instrument is not required in the first instance, as the solution is made up with greater accuracy and less trouble by weighing the carbonate and measuring the water. Its use in connexion with the cold dip is practically limited to checking the concentration after additions have been made.

2. The Thermometer.—A good thermometer is essential for the modified temperature dip. The type previously described (a mercury thermometer in a wooden frame) is convenient. Spirit thermometers are not satisfactory at such high temperatures. Many growers use a floating thermometer, or alternatively, hang one in the dip. The disadvantage of this practice is the greater liability to breakage. Excepting with maximum thermometers, all readings should be taken while the bulb of the instrument is well below the surface of the solution.

3. The Burette.—During recent years, the burette has been added to the equipment in some settlements, and with the use of standardized acid solutions and appropriate tables, determinations of the concentration of the caustic soda solution are made. The instrument, however, is of little practical use, as sufficient accuracy is obtained by weighing and in any case the appearance of the dipped fruit is the ultimate guide as to the required strength of the solution.

4. Measuring Vessels.—A kerosene tin, which holds approximately 4 gallons up to the holes for the handle, gives sufficient accuracy. In practice a preliminary measurement of the dip tanks and washing tanks to the required capacity is made and the distance from the bottom of the tank to the surface of the solution (or from the surface to the top of the tank) is marked on a notched stick. Thereafter the vessels are filled to this known capacity.

A pint measure for determining quantities of olive oil, a weighing scale for chemicals, and a 1-in. scale for measurement of the emulsion as previously described, are also necessary.

5. Cleaning Apparatus.—A "skimmer" should be kept at hand for removing accumulated scum from the dip.

For the cold dip, a perforated false bottom, below which the sediment and broken fragments of the vine can accumulate is of value in keeping the fruit clean. For the caustic-soda dips the usual practice is to suspend near the bottom of the tank (by wire hooks from the top of the tank) a number of small tins with their openings directed upwards. The sediment collects in these tins, which are withdrawn and emptied at suitable intervals.

After standing overnight, used dip solution may be cleaned to some extent by syphoning. The syphon is used in such a way that floating scum and sediment is left undisturbed and discarded when the bulk of the liquid is recovered. Dissolved and suspended matters are not separated by this method. Suspended matters, however, seldom appear in harmful quantities. On the other hand it is necessary to discontinue the use of a dip in which the dissolved substances, principally sugar, have any noticeable effect on the berries.

VII.—CIRCUMSTANCES AFFECTING CHOICE OF DIPS.

1. General.—In deciding which of the three dips will best suit his special requirements, the viticulturist should be guided by the following considerations :—

(*a*) The quality of his fresh fruit.

(*b*) The climate of his producing area.

(*c*) His personal experience of the processes.

(*d*) The practice of his neighbours in so far as his fruit will form a unit of the district pack.

(*e*) The capacity of his drying plant in relation to the quantity of fruit to be dried.

The transition period during which the cold dip and the modified temperature dip came into general use commenced in the drying season of 1925. Previously, dipping was practically limited to the boiling dip, though the modified temperature dip has been used on a small scale at various intervals during the past 30 years. It is apparent that the short experience (three seasons) of the new methods is insufficient to determine fully the average commercial results and suitability over a number of seasons.

2. The Quality of the Fresh Grapes.—By examination of the fresh fruit, it is possible to some extent to foretell the behaviour of the fruit during the process of drying.

A common example is wilted and partially-dried fruit, always present if harvesting is delayed, and frequently resulting earlier in the season if exceptionally hot weather or mistakes in irrigation have occurred. In its early stages wilting and natural drying on the vine is a feature of individual berries rather than of all the berries on the bunch. With present methods of processing, wilting berries invariably become much darker than the rest of the sample. The dark berries are very noticeable if the fruit is processed by the cold dip, owing to the light colour of the bulk of the sample. Under such conditions, the boiling dip has several advantages. It hastens drying whereby the darkening of the faulty berries is not so intense, and further it gives an intense brown to the good fruit in the sample, thereby tending to uniformity.

As faulty fruit usually occurs late in the season, the quicker drying rate from the boiling dip is of importance in giving a greater chance of avoiding bad weather and of preserving quality. With late drying and the probability of dews and humid conditions, the drying rate of fruit from the cold dip and the modified temperature dip may be so delayed that "blueing" and "browning" from enzyme and ferment action may occur on a large proportion of the berries. These features are not so much in evidence earlier in the season, when the shorter drying period results in a quicker concentration and consequently in a more efficient preservative action of the grape sugar.

The chief disadvantage of the cold dip results from its slower drying rate during the early stages giving a longer time for natural deterioration.

For this reason, the process proves successful only on good quality fruit and in districts where the fruit ripens sufficiently soon to warrant picking early in the season (15th February to 15th March).

Although deterioration occurs subsequent to picking and dipping, it has been found practicable, before processing, to determine the type of berry which is liable to deteriorate during slow drying. In general, large green berries, the small immature ones at the ends of the bunches, and any berries with a tendency to breakage at the point of attachment, tend to deteriorate. Such characteristics indicate faulty development, and are usually correlated with a low density of the "must." Faulty berries are present in greater proportion if the yields are abnormally high, or if the growth of the vines has been checked during the season.

Compared with the cold dip, the modified temperature dip gives a quicker drying rate during the earlier stages of the drying period. With late drying, when the number of berries exhibiting natural deterioration is likely to be excessive, this constitutes an advantage, as deterioration appears to commence in fully distended berries rather than in those partially dried and wilted.

3. The Climate of the Producing Area.—Grape drying is practised in a number of districts in Australia, under varying climatic conditions. The comparatively mild climate of some of these districts reduces the length of the drying season, by delaying maturation and by the early occurrence of low temperatures and dews.

Deterioration resulting from delayed drying, particularly if occurring in unfavorable weather, reduces quality considerably and in extreme seasons may render the fruit unsaleable as a dried product. In such circumstances, the boiling caustic dip, with its quicker drying rate, will probably give the best average results over a number of seasons.

4. Experience Necessary for Successful Processing.—Two essentials in successful grape drying (efficient dipping and satisfactory reduction of moisture) are dependent on human judgment. It is necessary that the processor should acquire correct standards in these particulars. This applies particularly to the newer methods which have been introduced comparatively recently and in which variations due to the individuality of the processor are much in evidence. The introduction of a new process to any district should be by demonstration on a small scale, and its general adoption should be preceded by evidence of its commercial success in the previous seasons.

5. The Practice of the District.—The continuance of a method that has been proved is warranted in any district until such time as other methods are shown to be more suitable, and until instructional work has been given to ensure a high and uniform standard of individual effort. In localities producing small amounts of fruit and where it is necessary to reduce types to secure sufficient quantity of saleable "lines," a common dip for each district is essential.

6. The Capacity of the Drying Plant.—In former years, when the use of the boiling caustic dip was common, the capacity of the drying racks was adjusted to give continuity to the work. The introduction of slower drying methods should be accompanied by the erection of additional drying racks. Otherwise it may be necessary to cease picking at times and over-maturation of the fruit and less favorable drying weather, may result. The drying period of fruit from the boiling dip, dried on a shaded rack in normal fine weather, is usually 9 to 10 days, the period fluctuating with changes in the weather. Cold dipping lengthens the drying period by approximately 50 per cent., while the period following the modified temperature dip is slightly less than that of the cold dip. Humid weather retards drying under all methods, but to a lesser extent if the grapes have been cold dipped.

VIII.—THE PRE-HARVEST IRRIGATION.

1. General.—In community settlements it is not possible to irrigate at the optimum time in respect to the maturity of the various varieties of fruits grown in those districts. The requirements are a watering late enough to last over the harvest period, but not so late as to interfere with maturation. This is not wholly attainable in most districts, but advance is being made in some areas by first watering early varieties, such as Zante currants ; completing the irrigation two or preferably three weeks before the normal date at which sultanas are ripe, and affording an opportunity of rewatering vineyards which were necessarily irrigated too early.

2. Effects of Irrigating Vines at or near Ripeness.—A decrease in density of the fruit juice—probably due to greater distention by water—invariably results if vines are irrigated when the grapes are nearly ripe. This feature may persist for a week or even more after irrigating. Grapes in this condition are more easily damaged and show a greater tendency to natural deterioration during drying. In the case of the Zante currant, it is accompanied by a retention of the undesirable red pigment. A delay in picking will correct inferior quality caused by delayed ripening, but this is bad policy, as it reduces the length of the drying period, and, in most seasons, the quality.

IX.—ECONOMICS.

With an export proportion in Australia of approximately 80 per cent. of the total production, it is necessary to produce dried fruit of a colour and quality suitable to the overseas requirements. Market reports on quality, though showing some inconsistencies, indicate that light coloured uniform fruit gives the best results. These reports are confirmed by the realizations of the fruit from the cold dip and the modified hot dip, and a continuance and expansion of these methods on standardized lines appears to be a sound policy, except in districts where the drying season is short. Objections have been made during the past two seasons to the multi-coloured samples and to the greenish tinge occasionally present. The multi-coloured fruit is mainly due to the application of the cold or the modified temperature dip to fruit of inferior quality, and to handling the grapes before they are sufficiently dry. Correction will come with experience, and with an extension of instructional work. Removal of the green colour by thorough bleaching entails extra expense, which so far has been justified by increased realizations.

In respect to the modified temperature dip, most of the mistakes of past seasons are due to weak dips, whereby the processor aimed at a very light brown, which too often was accompanied by a green tinge on some berries and natural deterioration of others. It appears sound policy to increase the strength until browning is definite on the dried product. In this way, though the small proportion of "fancy" samples may disappear, the faults of the past season will not be so much in evidence, while a higher average grade and greater uniformity will be obtained.

The best method or methods for areas of similar climate will ultimately be decided on processing costs considered in relation to realizations, and to the quantity of the special types absorbed in the various markets.

The transition period in respect to dips has been so recent, and variations due to individuality so great, that a decision on this point is not at present justified. It is certain, however, that the better quality secured in recent years has been reflected not only in a higher realization per ton but also in increased sales.

X.—SUMMARY.

1. The Boiling Caustic Dip—

(*a*) Prepare a solution containing 2½ lb. of caustic soda per 100 gallons of water.

(*b*) Test the efficiency of this dip by trial at boiling point. An immersion of one and a half seconds should be sufficient to remove all bloom, and slightly crack some of the berries.

(*c*) If not effective, add caustic soda progressively at the rate of ½ lb. to 100 gallons of dip solution, until the desired results are obtained. Excessive cracking indicates that the concentration is too great and it causes "stickiness" after packing. Testing is necessary after all additions.

(*d*) All dipping (including testing) should be done at the boiling point.

2. The Modified Temperature Caustic Dip—

(*a*) Prepare a solution containing 3 lb. of caustic soda per 100 gallons of water.

(*b*) Test the efficiency by trial, at 190° to 196° F. If effective, the bloom is entirely removed from all berries on an immersion of one and a half seconds. Removal of bloom may be accompanied by slight cracking.

(*c*) If not effective, add caustic soda progressively, at the rate of ½ lb. per 100 gallons of water until the desired results are obtained. Testing is necessary after all additions.

(*d*) All dipping, including testing, should be done at a temperature of 190° to 196° F.

(*e*) Spraying with the cold dip solution is essential during bad drying weather and preferable in normal weather. This does not materially alter the characteristics resulting from the dip.

3. The Cold Dip.—

(*a*) Prepare in the dip tank the required volume of solution containing 1 lb. carbonate of potash to 2 gallons of water.

(*b*) Add olive oil emulsion equivalent to one and a half pints of oil to 50 gallons of solution.

(*c*) Test by immersing the fruit for four minutes. If efficient, the bloom will be wholly removed, and an oily coating substituted.

(*d*) If not satisfactory, add oil emulsion progressively, at the rate of ¼ pint of oil per 50 gallons of water, until an effective test is obtained.

(*e*) Add an excess of emulsion equivalent to ½ pint of olive oil to 50 gallons dip solution, before using.

(*f*) Continue in use until slight traceries of bloom appear on the dipped fruit. Then add excess of emulsion as in (*e*).

(*g*) Additions of carbonate solution are made as a solution at original strength (1 lb. to 2 gallons of water), and entail further testing and additions to oil emulsion before using.

(*h*) The fruit should be sprayed with the "cold dip solution" at the third day, and thereafter at intervals of three or four days. A special spraying should be applied during or immediately after rainfall.

4. General—

(*a*) Fruit should be spread as soon as practicable after dipping.

(*b*) Quick drying improves quality. Therefore effective dipping and thin spreading are essentials.

(*c*) Removal and particularly bundling of partially-dried fruit invariably results in a multi-coloured sample, due to deterioration of individual berries to a varying degree.

(*d*) Bleaching of cold-dipped fruit should precede final washing, as otherwise regulation of moisture content is not possible.

(*e*) Thin spreading for exposure on hessian is essential for uniform results.

(*f*) The cold dip and the modified temperature caustic dip give best results in early and mid-harvest period, and with fruit of good quality.

H. J. GREEN,
GOVERNMENT PRINTER,
MELBOURNE.

PAMPHLET No. 7.

COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

THE

EXPORT OF ORANGES

By

W. RANGER
Manager of the Queensland Committee of Direction of Fruit Marketing

AND

W. J. YOUNG, D.Sc.
Associate Professor of Bio-Chemistry, University of Melbourne

MELBOURNE, 1928

By Authority:
H. J. Green, Government Printer, Melbourne

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C.1820.

CONTENTS.

The Export of Oranges.

1. INTRODUCTION.

(*a*) *Necessity for Export from Australia.*—Australia is stated to be second to the United States of America in the consumption of oranges per head of population, and at present consumes practically all the oranges she produces. In the near future, however, a large number of young trees will come into bearing, and even at present, an abnormally good season would yield a surplus over the consumption. An external market is therefore essential, if the industry is to progress.

This necessity for export has engaged the attention of the Citrus Associations of Australia, and the Council for Scientific and Industrial Research has been approached by the Victorian Association to undertake experimental shipments of oranges on a commercial scale.

(*b*) *Export past Experimental Stage.*—In view of the fact that oranges are successfully exported from other countries, and that standard methods of treatment have been evolved and are now in regular practice, the Council decided that the best interests of the Australian citrus industry would be served by making such information available, rather than by repeating experiments which have already been conducted elsewhere. In accordance with this decision of the Council, the writers have been asked to prepare a pamphlet embodying the practice obtaining in California and South Africa, with recommendations to the Australian industry.

It seems to the writers that practically no modification of the methods used successfully elsewhere need be made to meet Australian conditions. There appear to be no complicating factors.

2. METHODS USED ELSEWHERE.

A. California.

The citrus industry in California has adopted a standard method for fruit handling. The following description, therefore, applies to the fruit marketed within the United States as well as to the fruit exported. It takes a period of about 14 days for Californian oranges to reach the markets of the Eastern States, but frequently the fruit remains in the railway cars for much longer periods—up to 40 days. Of the fruit exported, probably that sent to Australia travels furthest. The sea journey is one of three weeks, which means that the fruit is probably a month old from the time of leaving the packing houses to arrival in Australia. Its keeping qualities in Australia are well known.

(*a*) *Picking.*—All the fruit is cut, and the pickers wear canvas gloves. At all stages the fruit is handled with the utmost care.

(*b*) *Packing House Procedure.*—The following is the general procedure adopted in the Californian packing houses. Some variation exists when the Brogdex system is used. This is described later.

1*st Operation.*—The field boxes are placed on an endless belt which carries them to the washer. Here the case is automatically tilted and the fruit emptied down an inclined plane into the washing tank. This tank contains a series of revolving brushes over which the fruit has to pass. The water has soap powder dissolved in it. The fruit then passes from this soaking tank through another series of brushes over which pure water is constantly sprayed. This completes the washing operation.

2nd Operation.—The fruit is passed into a tank containing a solution of borax and boric acid in the proportion of one part of the former to two parts of the latter in a 4½ to 5 per cent. solution. The temperature of the solution is maintained at 95° to 100° F. by means of a gas heater. This heater consists of a drum inside the after end of the tank. Through this drum pass several pipes open at both ends so that water from the tank can circulate freely through them. At this end the tank is deepened to accommodate the drum. Several gas flames impinge on these pipes and so heat the water. A small pump draws water from this end and delivers it through an outside pipe to the fore end of the tank. A slowly rotating series of paddles causes the fruit to travel forward and be immersed for the period required, viz., 5 minutes. The fruit is then delivered to an ascending platform, which is placed above the heater drum so that the fruit does not come into contract with the heated water ascending from the heated pipes. At the top of this platform the fruit meets a small spray of water which washes off any excess of borax. The strength of the solution is determined by a hydrometer, and the concentration is maintained by the addition of more borax and boric acid as required.

3rd Operation.—This consists of drying the fruit by passing it slowly through a drier where air is drawn over it by a series of fans. This operation takes 15 minutes.

After these operations the fruit presents a clean, bright appearance, much superior to the natural appearance when picked from the tree. The skin shows a polish that much enhances the value.

4th Operation.—The fruit is then passed to the grading belt, where girls hand-grade it for quality. Various belts convey it to the sizing machines.

5th Operation.—In the highest grade the oranges are passed through electrical marking machines which imprint the name " Sunkist " on each orange. This mark refers to quality only, and not to the size of the fruit.

6th Operation.—*Sizing.*—The sizing machine (similar to the type used in Australia) simply consists of wooden revolving rollers and a rope belt travelling longitudinally. The distance between the two gradually increases as the fruit is carried along by the rope belt while the rollers keep it revolving. Thus the smaller fruit is dropped first, and the larger fruit carried to the farther end.

7th Operation—Packing.—This is done by girls, who are paid 3d. per box for normal sizes, but 6d. per box for the small sizes. Small sizes are those from 2 inches to 2½ inches in diameter—490 to 252 per American box (equivalent to 326 to 168 per Australian box). To give every girl the same chance, the positions are changed every half hour, so that no girl is handicapped by being always on the same size.

8th Operation.—The packers place the full case on a travelling belt, where it passes to an automatic nailer, which nails the two ends. A metal strip is nailed over the middle of the lid by hand and the case is then ready to be loaded directly into the railway car or placed in the pre-cooler.

(*c*) *Size and Capacity of Cases.*—The orange case used has two compartments and measures inside 11½ in. x 11½ in. x 24 in. The net weight of the contents is 72 lb.

(*d*) *Brogdex Process.*—The Brogdex process consists of two parts—

1. The Borax or "Brogdite" treatment, effected in a somewhat different way from the method previously described; and
2. The Paraffin or "Brogdex" treatment, whereby the fruit is given an exceedingly thin coating of melted or dissolved paraffin wax. It is claimed that this restores the natural oil removed during the washing and borax operations, prevents evaporation, and that it is sufficient to slow down the rate of respiration of the fruit, but not sufficient to close the pores entirely. It also affords protection to any cuts on the skin of the orange.

The Brogdex Company claims a patent over this process, and of any process using borax. Most of the packing houses have been using the borax process without paying any royalty to the Company. The Company took action against one of the Associations, and recently the verdict was given in favour of the Company.

The procedure in houses using the Brogdex process is as follows :—

1. The fruit is first passed through a soaking tank containing a 4 per cent. solution of borax. No boric acid is used. The temperature is maintained at about 115° F. The fruit is completely immersed by a series of slowly revolving paddles as described previously, and the time of soaking is about 3½ minutes.
2. The fruit is then passed to the washer, where it is brushed in another borax solution of the same strength, to which soap powder is added when necessary.
3. The fruit passes through the drier.
4. The fruit passes under a thin spray or mist of paraffin wax supplied from a small electrically heated tank. A series of revolving brushes removes excess of paraffin so that a thin invisible coating only remains.

5. The fruit is carried by time-killing elevators in order that the fruit may dry, to the grading table, after which the operations are as previously described.

(*e*) *Colouring by Ethylene.*—A considerable amount of experimental work has been done in America on the colouring of fruit by means of ethylene gas. The procedure is to place the fruit in a fairly gas-tight room, and liberate ethylene gas every 24 hours in the proportion of 1 cubic foot of gas to 1,000 cubic feet capacity of the room. The rooms are ventilated each night for a short period, and the dose repeated. The temperature should be about 65° F. to 70° F.

The use of ethylene is standard practice in all American citrus packing houses for oranges received too green for ordinary packing, and for colouring lemons quickly when the market is favorable. The managers of the houses, however, are not enthusiastic over the process, and only use it when it is really necessary. They state that the fruit is softened by the treatment. Whilst, therefore, colouring by ethylene will be of value for local sales in Australia, it cannot, at the present stage, be recommended for export fruit.

(*f*) *Pre-cooling.*—Practically every citrus house has a cool store attached, and oranges are generally, but not invariably, pre-cooled before loading into railway cars. If the fruit be not pre-cooled it usually takes three or four days in the refrigerator cars to bring the temperature down to about 40° F. The aim is to carry the fruit between 38° F. and 42° F.

(*g*) *Stacking in Railway Cars.*—The cases are stacked on end seven wide by two high, with air spaces between to provide ventilation. As soon as one row of cases is stacked, two strips of wood are nailed to each case. The strips are the width of the car in length, about 1½ inches wide and about ½ inch thick. The idea is to brace the load and also provide ventilating space. When the two ends of the car have been stacked, or when only four more rows remain to be inserted, a "car squeeze" is used to force the cases together sufficiently to make room for these four rows. Otherwise there would not be sufficient room, and with three rows the car would be slackly stacked. The "car squeeze" is simply an expanding screw press.

Further details of the American citrus industry will be found in "What America Can Teach Us," a report by W. Ranger on his investigations of the American fruit industry in 1927, and published by the Queensland Committee of Direction of Fruit Marketing.

B. South Africa.

Approximately two-thirds of the oranges exported from South Africa are grown in the Transvaal; other citrus areas are situated in the Cape Province and in Natal. Citrus in South Africa is grown both with summer rainfall and winter rainfall.

The bulk of the fruit is exported from Cape Town, but a considerable quantity is also shipped from Port Elizabeth, in the Eastern Cape Province, and from Durban in Natal.

(*a*) *Picking and Packing.*—In South Africa the picking and packing are done by black labour with white overseers. In most of the citrus districts there are co-operative packing houses which are fitted with sizing machinery, but some growers still have their own packing houses where sizing is still carried out by hand. The fruit is cut and very carefully handled during the whole of the operations involved. It is not the usual custom to sweat the fruit. The oranges are cleaned, sized, wrapped in paper and packed in a $1\frac{1}{3}$-bushel case similar to the Australian export case.

(*b*) *Borax Treatment.*—Treatment with borax is not in general use, but is employed in some places. The largest citrus orchard in South Africa is that at Zebedelia (near St. Petersburg) in the Transvaal, and all the fruit is treated by the Brogdex process. The machinery has been imported from America for treatment with borax and paraffin as described in the previous section.

(*c*) *Transport by Rail.*—The fruit is sent to the port by rail in louvred trucks without ice. Even from the Transvaal to Cape Town (over 1,000 miles) no iced trucks are required; indeed, oranges are sometimes damaged through the frosts, which are very severe in the high lands over which the railway passes in the journey to Cape Town.

(*d*) *Inspection.*—At the port 5 per cent. of each consignment is inspected by a special staff of inspectors under the Department of Agriculture.

(*e*) *Pre-cooling.*—All oranges are pre-cooled to 40° F. before loading into the ships. In Cape Town this is done in the new Government Pre-cooling Station on the wharf. The train runs into an air lock on one side of the building, and the fruit cases are unloaded, tallied and inspected and put on to skids on wheels. These skids are then run into the pre-cooling chambers, and, after the temperature has been reduced, are wheeled out on to the wharf side of the building and transferred by the quayside hoists into the ship's hold. The fruit is thus not handled from the time it is put on to the skids until it arrives in the hold. This pre-cooling takes 12 to 24 hours.

In Durban pre-cooling is carried out at present in a privately-owned store, and the fruit is transported to the ship in refrigerator trucks. A pre-cooling station similar in design to that at Cape Town is to be erected by the Government on the wharf at Durban.

At Port Elizabeth, where there is no wharf, and where the ships anchor in the shelter of a breakwater, pre-cooling is carried out in specially constructed refrigerator lighters which take the fruit out to the ships.

(*f*) *Temperature during Transport.*—The temperature recommended is 40° F., and the hold is ventilated from time to time.

(*g*) *Control of Export.*—The export of fruit is controlled by the Perishable Products Export Control Board, on which one member out of six represents the citrus industry. This Board arranges shipping accommodation for the fruit, and allots space in the ships in order of priority of arrival of the fruit at the port. The Board employs an executive officer who has control of all transport and handling from the unloading from the trains to the loading into the ships' holds.

Cost.—The following charges are made to the growers in addition to the transport charges :—

Inspection, 5s. a ton (cubic measure) or about 4d. a case.

Pre-cooling, 5s. a ton or 4d. a case.

Handling charge, 5s. 6d. a ton.

Further details of the South African industry will be found in a report by W. J. Young in the *Journal of the Council for Scientific and Industrial Research*, Vol. 1, No. 2.

3. RECOMMENDATIONS.

The following recommendations are made to the Australian citrus industry :—

1. All the fruit should be cut and not pulled from the tree.

2. Gloves should be used whenever the fruit is handled, whether in picking, grading or packing.

3. Packing houses and equipment should be kept as clean as possible, and all discarded fruit should be cleared away at once. Mouldy fruit lying about in the packing house or in the bins of the machines is liable to contaminate the air and machinery with mould spores which may infect fresh fruit.

4. The borax process should be used. In this connexion attention is drawn to the fact that apparently the Brogdex Company holds an Australian patent over any process using borax. The terms under which it was prepared to license users in Australia are contained in the accompanying letter from the Company. Since this letter was written the Australian rights have been taken over by an Australian company.

" Brogdex Company,
Los Angeles, California.
5th August, 1927.

Pursuant to your understanding with our Vice-President, Mr. H F. Keenan, the matter of making a tentative proposition, embracing the terms upon which we would be willing to license the use of our processes to citrus packing Associations in that country, was discussed with our officers and the writer was authorized to submit the following proposition :—

We are willing to execute a license contract for the use of the ' Brogdite ' and ' Brogdex' processes and equipment for their application upon a royalty basis ; the licensee to pay a royalty or license-fee of 5½ cents per box for each U.S. standard box packed, or its equivalent. The U.S. standard box for oranges and lemons contains 72 lb. of fruit, and the royalty could be figured on that basis if the size of your cases and the weight of their contents differ from ours. The licensee would be required to pay the cost of construction, crating, freight, insurance and duty f.o.b. point of shipment, as well as the salary and expenses of our representative, who would go to your country and take charge of the installation and familiarize the licensee's employees with the machinery and methods of application. As you are aware, the equipment furnished by us for the application of these processes in this country is operated in conjunction with other standard packing house equipment consisting of conveyor belting, which carries the fruit from its last contact with the borax solution to the standard drier, the drier itself, conveyor belting taking fruit from the Brogdex (paraffin) applicator to the grading tables and belts, grading tables, sizers and bins for receiving the sized fruit.

Our smallest type of machine is that which we install in packing houses having a capacity of two carloads, or approximately 925 boxes per day, and the cost of that equipment crated, but not including freight, insurance, consular charges or duty, would be approximately \$4,650.00. The additional equipment necessary to complete such a standard packing house unit, which can be procured from Stebler Parker Company of Riverside, California, would include a 24-in. drier, 28-in. absorber, 18-in. roller elevator 24 feet long, for conveying fruit through the drier, double grader, with 24-in. belt, distributing bins and with 16-in. feeding conveyor 12 feet long for feeding and sorting for quality, f.o.b. Riverside, California, crated for export, at a cost of approximately \$2,875.00. The license contract would not contain any provision for maintenance, repairs or renewals of parts of our equipment by this Company, but would provide that extra parts and all materials forming the basis of the solutions used in our processes, with the exception of water, would be furnished at cost f.o.b. point of shipment. This contract would also provide for monthly payment of royalties on the basis of the amount of fruit packed during the preceding calendar month, for certified statements of the quantity of fruit packed each month, and for the appointment of a representative of this Company in your country to receive and forward royalties paid; the books of account and records of the licensee to be subject to inspection by our representative at reasonable times. The term of the license granted would be for the life of our Australian patents and any renewals thereof, and the licensee will be entitled to the benefit of any improvements in processes or apparatus. The licensee should acknowledge the title and ownership of this Company of such patents and the processes and apparatus covered thereby and agree not to assail such title during the life of the agreement, also not to use the equipment furnished for applying any other processes, and to abide by the instructions of this Company as to their manner of application. The contract would contain suitable provisions for termination in case of breach of contract and would give the licensee the right to terminate the contract at any time, upon six months' written notice to this Company in advance.

On 4th August we received telegraphic advice from out patent counsel in Washington, D.C., that a decision had been rendered in favour of this Company in the suit brought by us against American Fruit Growers, Inc., for infringement of our borax patent. The decision was sweeping and upheld all process and article claims relied upon by us. We consider this a great victory, which should enable us to soon come to terms with all citrus packers covering the use of our process under license.

With reference to water export of citrus fruit, our local licensees all agreed that the best results are to be obtained in citrus shipments made by vessels without refrigeration, where the fruit is packed in spaces below deck which are equipped with fans to insure the circulation of cool air throughout the hold, where the fruit is stored. It is our understanding that many freight carriers are now thus equipped.

Yours very truly,

BROGDEX COMPANY

By (Sgd.) WILLIAM R. MILLAN, Secretary."

It seems to us that the merits of the borax process are conclusively established. The fact that this process is universal in Californian packing houses and is being adopted in South Africa appears to be sufficient evidence.

The paraffin process seems to have considerable merits, and from the evidence supplied it would appear very desirable that this should be used for long distance shipments. As the Brogdex Company's royalty covers both processes, practically no additional expense would be incurred by using this.

5. The value of a distinctive mark on the individual orange needs no argument, and we believe it would be of considerable benefit to the industry. In this connexion, we suggest that the word " Kangaroo," such as appears on some of the orange wrappers, might be used as a distinctive mark for our first quality export fruit.

6. We recommend that the number of individual oranges in the case (instead of the diameter of the fruit) should be marked on the outside of the case. This affords much better information to the buyer and is in accordance with practice elsewhere.

7. Attention is drawn to the fact that the Californian case consists of two divisions each $11\frac{1}{2}$ in. x $11\frac{1}{2}$ in. x $11\frac{1}{2}$ in., and the cases are stacked on end so that there is no undue weight on the bottom layer. A similar case, but somewhat smaller, has been used for export from Australia, and it seems to us highly desirable that we should adopt a similar method of stacking on end, so that the heavier boards carry the weight. By this method there would also be better ventilation, as the bulge of the case would provide air spaces. The necessity for vertical dunnage might be obviated by this means. To prevent movement of the cases, due to shrinkage of the contents, it may be necessary to provide strips similar to the car strips used in California.

The records obtained by the officers of the Cambridge Low Temperature Station show that big variations in temperature occur in different parts of the ship's hold during the voyage, and pre-cooling of the fruit would reduce such irregularities. We would strongly advise, therefore, that all fruit be pre-cooled to 40° F. before shipment.

8. No fruit should be exported from any district where there is no packing house properly equipped in accordance with these recommendations.

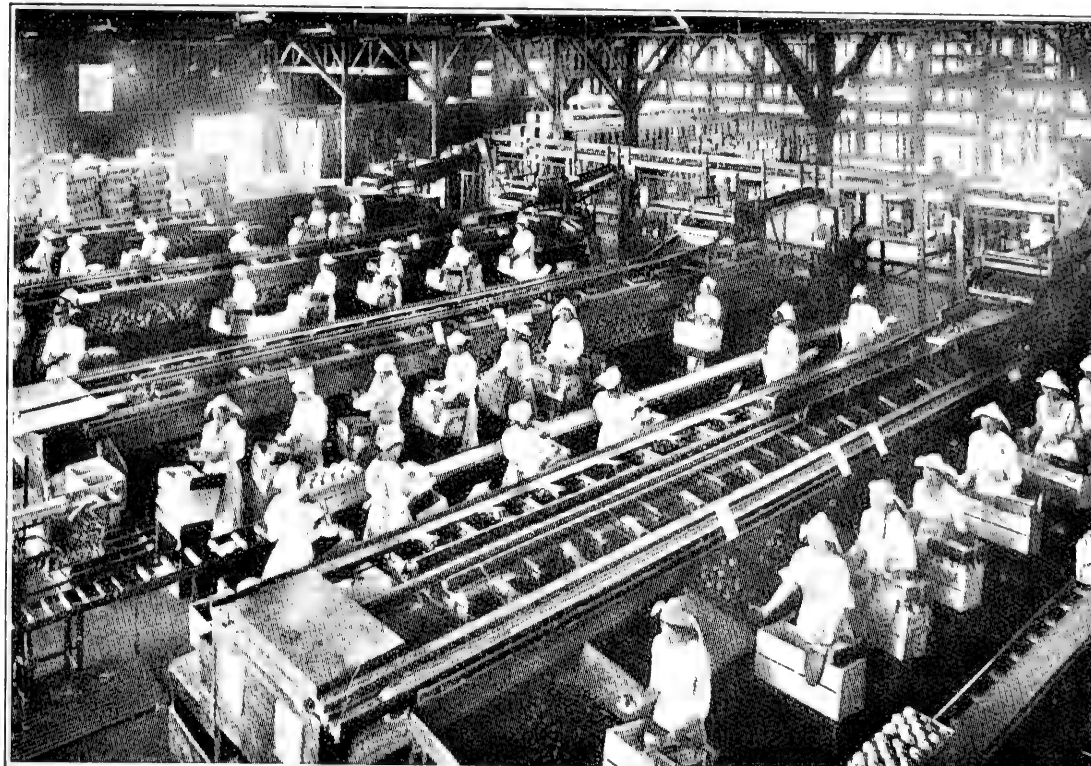

PLATE I.—ORANGE PACKERS AT WORK IN A CALIFORNIAN PACKING HOUSE.

Block kindly furnished by the Queensland Committee of Direction of Fruit Marketing.]

PLATE II.—HARVESTING CITRUS FRUIT IN CALIFORNIA.

(Special Curved Clippers are used to prevent the projection of stems. In addition all pickers use canvas gloves.)

Block kindly furnished by the Queensland Committee of Direction of Fruit Marketing.]

PLATE III.—THE PRECOOLING STATION AT CAPETOWN.

Side view, showing the Docks and Table Mountain in the rear.

Photograph kindly furnished by the Authorities at the Station.]

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PAMPHLET No. 8

COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

METHODS FOR THE EXAMINATION OF SOILS

By

J. A. PRESCOTT, M.Sc.
(Professor of Agricultural Chemistry)
and
C. S. PIPER, B.Sc.
(Assistant Chemist)

Waite Agricultural Research Institute, University of Adelaide, South Australia

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Council for Scientific and Industrial Research

MEMBERS

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PREFACE.

The following pamphlet is the result of a realization that greater co-ordination is desirable between the various laboratories in Australia engaged in advisory or systematic work on soils. Up to the present time the methods adopted have been largely determined by the special outlook of the department concerned with probably a general tendency to follow analytical practices and standards common in the United States. The rapidly changing outlook in the chemistry of soils brought about in recent years by the newer work on hydrogen-ion concentration and replaceable bases, and the increasing importance of soil investigations in Australia in connexion with the problems being investigated under the auspices of the Council for Scientific and Industrial Research, make the present time a convenient one for attaining such uniformity of method throughout the Commonwealth.

The methods recommended are the result of some years of experience, together with critical studies of technique conducted at the Waite Institute during the past three years in dealing with Australian soils, and are suggested as a basis for discussion in reaching such standardization.

Adelaide,

January, 1928.

C.2760.—2.

CONTENTS.

GENERAL REFERENCES.

In compiling these methods, the following text-books have been consulted :—

Washington, H. S.—Manual of the Chemical Analysis of Rocks, 3rd edition. 1919.

Hillebrand, W. F.—The Analysis of Silicate and Carbonate Rocks. U.S. Geological Survey Bulletin 700. 1919.

Association of Official Agricultural Chemists.—Official and Tentative Methods of Analysis. 2nd edition. 1925.

Russell, E. J.—Soil Conditions and Plant Growth. 5th edition. 1927.

In many cases the methods have had to be suitably adapted to the conditions encountered in soil analysis.

In addition to the above, the original papers have been consulted for some of the methods of analysis, such references being given in the text.

REAGENTS.

Throughout the following methods, when reference is made to concentrated reagents, the following strengths are understood :—

Concentrated sulphuric acid ..	S.G. 1.84
Concentrated hydrochloric acid ..	S.G. 1.18
Concentrated nitric acid	S.G. 1.42
Fuming nitric acid	S.G. 1.50
Concentrated ammonia	S.G. 0.91

When referring to diluted reagents, the strengths are indicated, as for example, dilute sulphuric acid (1+4) means one part of the above concentrated sulphuric acid diluted with four parts (by volume) of water.

I.—FIELD METHODS.

1. General.

The choice of the methods of field examination and of sampling depends on the purpose for which the sample is required. Where the sample is to be representative of a given area of land, it will be necessary to take a number of samples scattered uniformly over the field or block which is to be examined. As examples of laboratory determinations requiring such composite samples may be mentioned—moisture determinations in fallowed land for judging purposes in fallow competitions, the salt content of irrigated soils, or the lime requirement of acid soils. For such sampling a cylindrical borer such as is recommended by E. J. Russell* is of value. (Fig. 1a.)

It is preferable to sample where possible on stubble land. Where there is a surface mulch, this should be sampled separately and swept clear of the consolidated layer below. This is very important where water soluble material is to be determined. Under Australian conditions the soil is frequently very dry and hard, and it is almost hopeless to use the cylindrical sampling tools. The ordinary post-hole auger of commerce (Fig. 1b) is an excellent substitute in this case, and can be obtained down to 3 inches in diameter. The main objection to the use of this auger is the fact that the diameter of the top is slightly larger than at the bottom. The combined cutting and digging edge makes this tool, however, easily the most serviceable for general use in hard ground.

Where only small samples are required, as for moisture determination or bacterial numbers, particularly in a growing crop, the Fränkel borer (Fig. 1d) may be recommended where the ground is reasonably moist. This borer is pushed down or hammered down in a closed condition and filled by a clockwise rotating movement which opens the receptacle and scrapes the soil into the opening; a half turn in the opposite direction closes the opening again, and the borer can be withdrawn.†

For survey work it is not necessary to keep samples from every hole. The auger is used principally to determine the nature of the soil and the character of the soil profile. For light soils, reasonably moist, a screw auger with a specially cut digging edge is rapid and convenient (Fig. 1c). The pitch of the screw should be sufficiently narrow to bring up the sample. For harder soils the post-hole auger is again the most rapid sampling tool. When a type sample is required, no attempt should be made to secure a mixed sample representative of a given area. The sample is intended to represent soil conditions at some particular point on the map, and this position must be carefully selected so as to be representative of the soil formation which has been defined from previous bores over the area. To determine the nature and magnitude of the natural variations from type a number of independent samples should be collected. The method usually employed by Australian land surveyors

* Russell, E. J., Soil Conditions and Plant Growth, p. 453 (1927).

† In heavy clay Egyptian soils reasonably moist, this sampler has been used successfully to depths of 160 cm. (Balls, W. L., *Journ. of Agric. Sci.*, *5*, p. 469 (1913); Prescott, J. A., Sultanic Agric. Soc. Bull. No. 7, 1921).

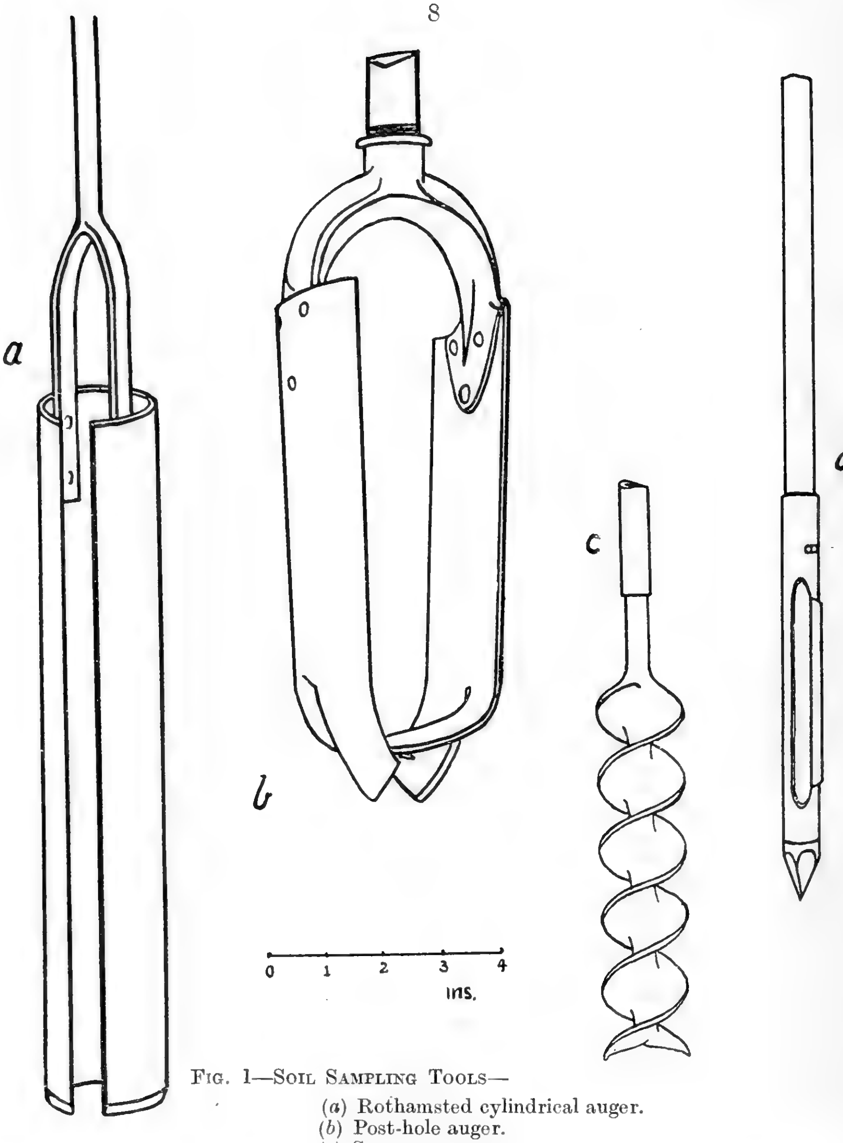


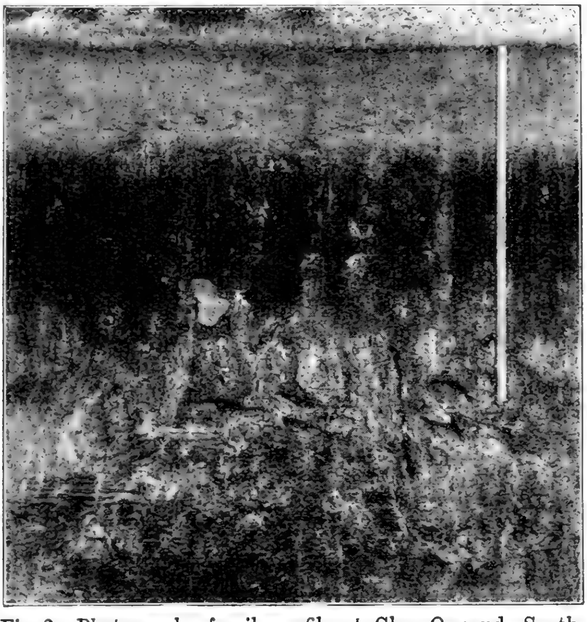
FIG. 1—SOIL SAMPLING TOOLS—
(a) Rothamsted cylindrical auger.
(b) Post-hole auger.
(c) Screw auger.
(d) Fränkel borer.

is to dig a pit by means of a pick, crowbar, and spade, sufficiently large and deep to make it possible to examine the profile of the soil. This system is similar to the one recommended by Glinka.* From the side of such a pit it is possible to remove samples, horizon by horizon, and the Russian workers frequently transport the whole of such a sample profile in a metal frame which can be pressed into the side of the pit. The colour and texture of the profile should be noted, and a tinted drawing made recording the colour of the various layers and their depths. Where the original vegetation is known, as is usually the case in Australia, this should also be noted.

* Glinka K. Die Typen der Bodenbildung, p. 12 (1914)

2. Soil Profiles.

The soil profile is assumed to be made up of three zones or horizons which, in international nomenclature, are known as the A, B, and C horizons. A is the eluvial horizon or zone of leaching, B is the illuvial horizon or zone of deposition, C is the zone of unchanged drift or purely mechanically modified rock material. Under reasonably high rainfall conditions, the zone A is depleted of lime and of clay—clay being usually accumulated in the B layer. The surface zone may be enriched by the



A_1

A^2

B^1

B_2

C

Fig. 2—Photograph of soil profile at Glen Osmond, South Australia. Vegetation type. *Eucalyptus odorata* savannah.

Horizons: A_1 zone of leaching with slight humus accumulation.
A_2 zone of leaching.
B_1 zone of accumulation—clay.
B_2 zone of accumulation—calcium carbonate.
C parent soil-forming material.

addition of humus from the native vegetation. Under more moderate rainfall conditions, particularly with a well marked dry period in summer, the lime removed from the A horizon appears in the lower part of the B horizon. Eventually it ought to be further possible to find a place for the Australian soil types in some international system of classification,* but at present information available is too incomplete for such a classification to be attempted.

II.—PREPARATION OF SAMPLE.

The sample taken in the field should be thoroughly mixed, any large pieces being broken down by hand into smaller pieces averaging about

* For a summary in English of the international system of soil classification, see Robinson, W. G. *Geological Magazine* 61, p. 444 (1924). Shantz H. L. and Marbut C. F.: The Vegetation and Soils of Africa (1923).

half-an-inch in diameter. The sample should be spread out on a piece of sacking or strong brown paper, and a carefully sampled representative portion of about 3 lb. taken. Calico bags are the most convenient for this purpose. A label with any relevant notes is placed in the bag with the sample. For most purposes the soil is to be air-dried and then ground in a convenient mortar with a wooden pestle, or at least under such conditions as will not actually break down any of the ultimate particles of the soil. The soil sample should be ground to pass through a sieve with circular holes 2 mm. in diameter. For special purposes where small quantities of soil are to be weighed, say, for nitrogen or for calcium carbonate, it is desirable that such samples should be weighed from material which has been ground still further, say, to pass 0.5 mm., mixing the coarse portion back in the sample.

III.—MECHANICAL ANALYSIS.

1. General.

The purpose of the mechanical analysis is to determine the proportions in the soil of the various soil particles. While it is possible by the use of such means as the Odén-Keen balance to obtain a complete representation of the size distribution of the ultimate soil particles, it is necessary for general purposes to adopt some conventional scheme of classification for these particles. Below are given the three most important systems in use at the present time, and the British system of units is adopted as standard in this publication. It is easily possible to transform values obtained in this way into the international system by the graphic method proposed by Robinson* and outlined below.

TABLE 1.

CLASSIFICATION OF SOIL PARTICLES FOR PURPOSES OF MECHANICAL ANALYSIS.

System.	Description of Particles.	Diameter of Particles.	Settling Velocity.
		Limiting values.	
International	..	2000u (2 mm.)	
		200u (0.2 mm.)	10 cm. in 5 secs.
		20u (0.02 mm.)	10 cm. in 7½ mins.
		2u (0.002 mm.)	10 cm. in 8 hours
British	Fine gravel ..	2 —1 mm.	
	Coarse sand ..	1 —0.2 mm.	
	Fine sand ..	0.2 —0.04 mm.	
	Silt	0.04—0.01 mm.	30 cm. in 5 mins.
	Fine silt ..	0.01—0.002 mm.	12 cm. in 20 mins.
	Clay ..	Below 0.002 mm. (Calculated value 0.0014 mm.)	8.6 cm. in 24 hours
United States — Bureau of Soils	Fine gravel ..	2 —1 mm.	
	Coarse sand ..	1 —0.5 mm.	
	Medium sand ..	0.5 —0.25 mm.	
	Fine sand ..	0.25—0.10 mm.	
	Very fine sand	0.10—0.05 mm.	
	Silt	0.05—0.005 mm.	
	Clay ..	Below 0.005 mm.	

* Robinson, G. W. *Journ. Agric. Sci.*, 12, pp. 306–321, 1922; ibid. 14, pp. 626–633, 1924.

No attempt has as yet been made to express these international units by any popular or scientific terms beyond the recognition of the German names originally suggested by Atterberg—"Sand," "Mo," "Schluff," "Ton." Corresponding English equivalents that suggest themselves are coarse sand, fine sand, silt, and clay, which would be satisfactory if the system were specified at the same time.

The interpolation from the British system to the international system may be carried out by plotting the accumulated values for the successive fractions. The conventional dimensions or settling velocities of the particles are plotted on a logarithmic scale. It has been shown by G. W. Robinson* that the curves so obtained are smooth, and that results obtained on one scale can readily be transferred to another scale by interpolation.

In Fig. 3 are given examples of such summation curves for South Australian soils.

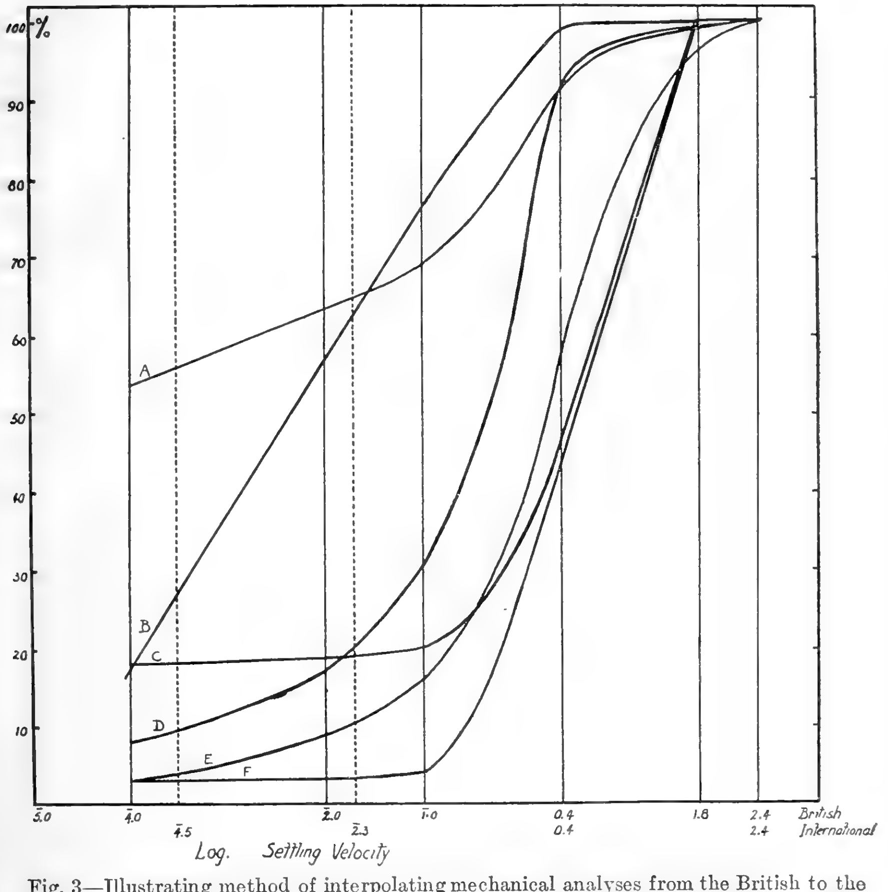


Fig. 3—Illustrating method of interpolating mechanical analyses from the British to the International system.

* Robinson, G. W. *Journ. Agric. Sci.*, 14, p. 626, 1924.

The actual analytical data and the interpolation to the international system are given in Table 2.

TABLE 2.

ILLUSTRATING DETERMINATIONS OF MECHANICAL ANALYSES OF SOME SOUTH AUSTRALIAN SOILS WITH INTERNATIONAL VALUES CALCULATED BY INTERPOLATION FROM FIG. 3.

Locality.	A. George-town.	B. Spalding.	C. Pinnaroo.	D. Macclesfield.	E. Mount Pleasant.	F. Copeville.
Laboratory No. ..	101.	99.	273.	12.	9.	304.
	%	%	%	%	%	%
BRITISH UNITS.						
Fine gravel ..	1.3	0.2	—	1.3	4.0	—
Coarse sand ..	7.7	0.9	53.2	6.6	37.7	56.8
Fine sand	22.2	22.3	26.8	61.3	42.2	39.1
Silt	5.4	19.4	1.1	13.6	6.9	0.9
Fine silt	9.6	39.9	1.0	9.2	6.2	0.1
Clay	53.8	17.3	17.9	8.0	3.0	3.1
	100.0	100.0	100.0	100.0	100.0	100.0
INTERNATIONAL UNITS.						
2 mm.—0.2 mm. ..	9.0	1.1	53.2	7.9	41.7	56.8
0.2 mm.—0.02 mm.	26.2	35.9	27.8	71.9	47.8	39.8
0.02mm.—.002 mm.	9.0	36.3	1.0	10.5	6.4	0.3
Below 0.002 mm. ..	55.8	26.7	18.0	9.7	4.1	3.1
	100.0	100.0	100.0	100.0	100.0	100.0

The newer methods of mechanical analysis are reviewed by S. Oden.* The pipette method of mechanical analysis was first proposed by G. W. Robinson,† who also showed the necessity of treating soils with hydrogen peroxide to decompose the organic matter.‡ The pipette method was investigated by a sub-committee of the Agricultural Education Association,§ and the method was finally adopted as official by that Association.‖ The method has also been independently investigated at the Waite Institute, and the detailed procedure of the latter modification is given below. The method as outlined can be relied upon to give accurate results even on soils containing quantities of calcium carbonate and gypsum.

2. Standard Pipette Method for Mechanical Analysis.

(*a*) *Moisture.*—Weigh out two portions of air-dry fine earth, each of 10 gms., into two ignited and weighed silica basins. Dry in an oven at 100° until there is no change in weight—usually nine hours is found to be sufficient. The semi-circular oven (Gallenkamp, Cat. No. 3137 or 3132) allowing the samples to be dried in a current of warm, dry air has been found to be very convenient for this purpose, samples being usually dry in four to six hours. The water jacket of such an oven is to be filled with 5 per cent. glycerine in water.

* Oden, S. *Soil Sci.* 19, pp. 1–35 (1925.)
† Robinson, G. W. *Journ. Agric. Sci.* 12, pp. 306–321 (1922.)
‡ Robinson, G. W. *Journ. Agric. Sci.* 12., pp. 287–291 (1922.)
§ *Journ. Agric. Sci.* 16, pp. 123–144 (1926.)
‖ The Agricultural Education Association's Official Pipette Method has been modified while this pamphlet was actually in press. (*Agricultural Progress,* 1928 5, pp. 137-144).
The two most important modifications adopted are:
(*a*) The percentage of the fractions are now reported on the oven dried (105°C) and not on the ignited basis.
(*b*) The settling times used for the separation of the fractions are different: two fractions only (International clay and silt) are determined instead of three originally (clay, fine silt, and silt).
For the 2 mm. sieve, the Agricultural Education Association has now adopted a No. 70 I.M.M. standard wire gauze, the aperture being .18 mm. The No. 90 I.M.M. standard gauze being used at the Waite Institute has a diagonal aperture of approximately .2 mm.

Revised British Method for the Mechanical Analysis of Soils.

As a result of discussions by the International Society of Soil Science and at the Imperial Agricultural Research Conference in 1927, the Agricultural Education Association of Great Britain has recently revised the official method to bring it into line with international procedure and standards. A full account of the revised method is to be found in *Agricultural Progress* (1928), pp. 137–144. Australian workers are strongly recommended to adopt the new standards.

The procedure for the preparation, dispersion, and sampling can be taken as given in the present pamphlet. The first sampling representing silt + clay is made at the 10 cm. depth after an interval of 4 minutes 48 seconds, the second sample representing clay is made at a depth of 10 cm. after 8 hours. The remaining fraction, fine sand, is determined directly on the residue by successive decantations after settling for 4 minutes 48 seconds in a depth of 10 cm. A new procedure is that the samples are dried at 105° C. and not ignited, although for some purposes the ignited weight, particularly of the clay fraction, may be of additional value. The 0.2 mm. mesh sieve recommended for the separation of coarse sand from fine sand is the I.M.M. sieve No. 70, having a square hole of 0.18 mm. side. The slight wear and tear in use brings the apertures nearly to the 0.2 mm. size.

It is further recommended that the depth of a pipette sampling, or conversely the time of sampling, should be adjusted to the viscosity of the water as affected by the temperature. If at 20° C. (the standard temperature), the depth of sampling is h, the appropriate depth at temperature T is given by Kh where K has the values as given below :—

T	5	10	15	20	25	30°C.
K	0.660	0.784	0.880	1.000	1.125	1.257

The new British scale is then as follows :—

	Depth.	Time.	Corresponding Diameter.
Clay	10 cms.	8 hours	0.002 mm.
Silt	10 cms.	4 mins. 48 secs.	0.02 mm.
Fine sand	Separated by sieve		0.2 mm.
Coarse sand			2.0 mm.

The results to be reported as percentages on the air-dry soil in the revised British method are therefore :—

(1) Coarse sand, remaining on 0.2 mm. sieve.

(2) Fine sand, obtained by sedimentation.

(3) Silt } obtained by pipette sampling.
(4) Clay }

(5) Moisture in air-dry soil.

(6) Carbonates.

(7) Loss by solution in peroxide—HCl treatment.

(8) Difference (organic matter removed by hydrogen peroxide and errors of experiment).

Total = 100.

C.2760.

(*b*) *Loss on Ignition.*—After determining the moisture, place the silica basin containing the dried soil over a Meker burner turned very low. Gradually increase the flame until, after fifteen minutes, full heat is applied. Then stir three times at five-minute intervals, using a spatula. Transfer to a hot muffle and finish the ignition for fifteen to twenty minutes at a bright red heat. Cool in a desiccator and weigh.

$$\text{Loss in weight} \times 10 = \% \text{ "loss on ignition."}$$

(*c*) *Loss on Acid Treatment.*—Weigh out 10 grms. of soil and transfer to a 250 ml. beaker. Add 100 ml. of N/5 hydrochloric acid, and stir well. Allow to act for one hour, stirring at intervals. If more than 2 per cent. of calcium carbonate is present in the soil, in addition to the 100 ml. of N/5 acid, add 1 ml. of 2N hydrochloric acid for each per cent. of calcium carbonate present. Filter through an 11 cm. Whatman No. 44 filter paper, which has previously been dried in the water oven and weighed. Wash with three portions of 40 ml., 20 ml., and 20 ml. respectively of the fifth normal acid. Then wash with distilled water until the filtrate is no longer acid. Dry in the water oven in a current of warm, dry air for 7–10 hours, or to constant weight, cool in a desiccator, and weigh quickly. The difference between the first weight (10.000 grms. plus the weight of the dried filter paper), and the final weight equals weight of moisture plus "loss on acid treatment." Deduct the weight of moisture and multiply by 10 for per cent. "loss on acid treatment."

(*d*) *Grading into Fractions.*—(i) *Treatment with Hydrogen Peroxide.*—Weigh out 25 grms. of the air-dried soil into a tall 800 ml. pyrex beaker. Add about 50–60 ml. of 6 per cent. (20 vol.) hydrogen peroxide (free from sodium, barium, chloride, phosphate, and sulphate).* Allow the reaction to proceed in the cold for five minutes, and then stand the covered beaker on the top of a boiling water-bath, watching it carefully and removing it when necessary to avoid the soil frothing over. Then proceed under (*a*) or (*b*) according to the type of soil.

(*a*) for soils containing small to moderate amounts of organic matter.

After fifteen minutes on the water-bath, place the beaker in the bath for five minutes, stirring the contents to avoid frothing over. Remove and add a further 25–40 ml. of hydrogen peroxide, and after a minute or two replace the beaker on the top of the bath for ten minutes and then in the bath for five minutes as before. Rinse the cover and the sides of the beaker with water from a wash bottle and dilute to about 150 ml. Bring to a boil over a burner or hot plate and keep gently boiling for five minutes, watching carefully to avoid frothing over. Place aside to cool.

(*b*) for soils containing larger quantities of organic matter.

After the first vigorous action on the water-bath has ceased (say, after 5–10 minutes), add a further 30 ml. of hydrogen peroxide, and replace the beaker on the bath for ten minutes. If the soil is particularly rich

* A 20 per cent. solution of hyperol (the white crystalline compound of hydrogen peroxide and urea) has been used instead of 20 volume hydrogen peroxide. The solution should be filtered through a Buchner funnel to remove small quantities of paraffin wax which are invariably present.

in organic matter, add another 30 ml. of hydrogen peroxide and heat on the water-bath for a further ten minutes. Then place the beaker in the water-bath for five minutes. Remove and add 25–40 ml. of hydrogen peroxide, heating on the bath for ten minutes and in the bath for five minutes, and then boiling exactly as under (*a*) above.

(ii) *Acid Treatment and Filtration.*—When the contents of the beaker are cold, clean the sides with a rubber pestle made by fixing a soft rubber stopper on to the end of a glass rod and add 25 ml. of 2N hydrochloric acid. Should more than 2 per cent. of calcium carbonate be present, add an extra 2.5 ml. of the 2N acid for each per cent. present. Then dilute until the volume is approximately 250 ml., and thoroughly rub the soil with the rubber pestle. The above operation is to be commenced early in the morning so as to give a whole day for the first part of the filtration.

Special types of soil have been encountered in which the calcium carbonate occurs in a dense compact form, only slowly attacked by the dilute acid. Such soils should be left in contact with the required quantity of 2N acid overnight, instead of the one hour for ordinary soils. The 10 grm. portion used for the determination of the loss on acid treatment should be treated with the acid for a similar period. Soils containing appreciable quantities of gypsum are also likely to give trouble at this stage. Shaking the soil sample (after the peroxide oxidation) with 500–750 ml. of 1 per cent. hydrochloric acid for 8–16 hours is necessary to dissolve the gypsum completely. Six portions of N/5 hydrochloric acid, instead of four, should also be used to wash the sample when filtering. When this modification is used the loss on acid treatment should also be determined by shaking 10 grms. of soil with 200–300 ml. of 1 per cent. hydrochloric acid as above. The SO_4 can then be determined in an aliquot of the undiluted filtrate, and the residue is washed as usual, dried, and weighed.

Allow the acid to act on the soil for one hour, rubbing well at intervals. Test with litmus to see that an excess of acid is present, then filter through a 12.5 cm. Buchner funnel fitted with an 11 cm. Whatman No. 50 filter paper. Wash with four successive portions of 50 ml. each of the fifth normal hydrochloric acid, draining completely between each addition. Then wash thoroughly with water, adding it in small portions at a time, and draining completely between each addition. Continue the filtration until three litres have passed through the funnel (or in the case of very slow filtering soils pass as much through as possible by three days' continuous filtration).

(iii) *Dispersion with Ammonia.*—After the washing is complete, transfer the soil from the funnel to a silica or porcelain basin of about 100 ml. capacity, using a spatula and two clock glasses to aid in the transference. Leave the filter paper on one of the clock glasses. Add 10 ml. of concentrated ammonia to the bulk of the soil in the basin. Into a second basin, wash the funnel and clock glass, using a camel hair mop, and a stream of water from the wash bottle. Also remove the last traces of soil from the filter paper by pouring about 3 ml. of ammonia on to it, rubbing with the brush, washing into the second basin, and then rolling the paper into a ball, alternately wetting and squeezing it two or three times.

Then using the camel-hair mop or a rubber pestle, work the soil and ammonia in the first dish into a thick cream, rubbing thoroughly to bring about complete dispersion of all the soil particles. It is essential to do this properly. Continue working the soil, adding water gradually (10–20 ml. portions at a time) until the basin is about three-quarters full. Place aside to stand for a minute or two, then decant through a standard 90-mesh sieve into the sedimentation cylinder. Again rub up the residue with more water, allow to stand and decant. Repeat this twice more or until nearly all the clay has been separated from the sand. When most of the clay has been removed, the rubber pestle will be found better than the brush for working the soil. Also pour the liquid from the second basin on to the sieve, rub thoroughly any sediment in the basin and transfer completely to the sieve.

Then transfer the sandy residue from the first basin to the sieve, rubbing it very gently with the brush and washing as much through as will go. Finally clean the brush in about six portions of water in one of the dishes, washing the residue on to the sieve each time. Rinse the lower rim of the sieve, place it on a tin tray, and dry in the oven.

After the above operation, the contents of the cylinder should be from one-half to three-quarters full. It is capped and placed in the shaking machine. Shake overnight.

An alternative method of dispersion is at present under investigation, so far with entirely satisfactory results. Use is made of a fan motor directly coupled to a $2\frac{1}{8}$-in. propeller blade, made from pure nickel, as suggested by G. J. Bouyoucos.* The motor is clamped vertically, as in the commonly used drink mixer, the propeller being attached to the spindle of the motor by means of a stout rod of pure nickel, 5 inches long. Six vertical baffle-plates, each $1\frac{3}{4}$ inch long and $\frac{1}{4}$ inch wide, attached at the top and bottom to horizontal rings of nickel, fit into a 600 ml. pyrex beaker. This baffle-plate structure is rigidly fixed into the beaker by a nickel rod, projecting upwards and bending over the top of the beaker. The beaker fits into a metal recess, just large enough to prevent any lateral movement, immediately underneath the motor. The propeller is then about $\frac{3}{8}$ of an inch above the bottom of the beaker. The baffle-plates are necessary to secure complete dispersion, as they tend to oppose the rotation of the liquid when the propeller is in motion.

Below is given the method of procedure.

Transfer the soil from the funnel into a 600 ml. pyrex beaker, using two clock glasses and the camel-hair mop, as previously. Add 15 ml. of ammonia to the beaker. Wash the Buchner funnel, clock glasses, and filter paper into the same beaker, and finally wash the brush. The volume of water used must not exceed 200–225 ml. Place the nickel baffle-plate grid in the beaker, fixing it rigidly in position. Place the

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* Bouyoucos, G. J. *Soil Sci.*, 23, pp. 319–330, (1927.)

beaker in the cavity under the motor, and set the latter in motion, controlling its speed by means of a rheostat if necessary. After five minutes' stirring, stop the motor, temporarily release the baffle-plates to free any soil held between them and the sides of the beaker, and then continue the stirring for a further ten minutes. Rinse the propeller blades into the beaker, remove and rinse the baffle-plates, and allow the beaker to stand for one minute. Then decant the liquid through a standard 90-mesh sieve into the sedimentation cylinder, and transfer the sandy residue to a silica basin. Rub this once or twice with a rubber pestle to insure the complete removal of the clay, pouring off the turbid liquid each time. Then transfer the sand to the sieve and wash as much through as will easily pass the sieve, until the cylinder is about one-half full. Cap the cylinder and place it in the shaking machine.

(iv) *Pipetting the Samples.*—After 16–18 hours' shaking, remove the cylinder from the machine and fill it to the 1,250 ml. graduation, rinsing the cap into the cylinder and replacing it on top. Then shake for 30–40 seconds by hand to insure uniformity of the suspension. Remove the cap and place the cylinder aside to sediment.

After exactly five minutes, withdraw a sample of 20 ml. from a depth of 30 cm. below the surface, using a special long-stemmed pipette supported by passing it through a block of cork. The pipette is to be closed with the finger while entering the suspension, and continuous gentle suction, produced by the device described below, is to be used for filling the pipette. Transfer the 20 ml. of suspension to a silica basin previously ignited and weighed. Vitreosil basins size B3 or F2 are most suitable.

If a $\frac{1}{4}$-in. length of a thick walled and small-bore rubber tubing, or a slice of a rubber stopper, is placed on the lower stem of the pipette, its position can be so adjusted that when the pipette is passed through the sheet of cork the tip will be exactly 30 cm. below the surface of the liquid. The pipette must, of course, always be used in the same cylinder.

Similarly, the pipettes for the second and third samples should be adjusted so that their tips come exactly 12.0 and 8.6 cm. respectively below the surface of the liquid. (The surface of the liquid does not correspond to the graduation mark of the cylinder after the first sample has been withdrawn.)

Evaporate to dryness on the water bath, and ignite in an electric muffle, gently at first, and finally at a bright-red heat for fifteen minutes. Cool in a desiccator and weigh.

Similarly, after twenty minutes from the commencement, remove a second 20 ml. portion from a point 12 cm. below the surface. Evaporate and ignite as before. A third sample is to be withdrawn, after 24 hours' sedimentation, from a depth of 8.6 cm., evaporated, and ignited as before.

% of silt = difference in weight between first and second samples $\times \frac{1250}{20} \times \frac{100}{25}$ = difference in weight $\times$ 250.

% of fine silt = difference in weight between second and third samples $\times$ 250.

% of clay = weight of third sample $\times$ 250.

(v) *Separation of the Fine Sand.*—After the removal of the clay sample, syphon off the suspension to within 1 inch of the bottom, and wash the residue in the cylinder into a tall 500 ml. pyrex beaker. Add any material which passes through the 100-mesh sieve after drying (see below). Then separate the fine sand by the usual decantation of 100 secs., using a height of 10 cm. of water. Towards the end thoroughly rub the residue twice with a rubber pestle to remove the last of the finer fractions. The last few decantations should be timed so that the 100 second period occurs in the middle of the pouring off. When no further material remains in suspension in 10 cm. for 100 seconds, transfer the fine sand into a weighed silica basin, decant the excess of water, and then evaporate to dryness and ignite over a Meker burner. Cool in a desiccator and weigh.

% fine sand = weight of fine sand $\times$ 4.

(vi) *Separation of the Coarse Sand and Fine Gravel.*—When the sieve has been dried, carefully rub the residue on it with the forefinger, and then sift for about a minute until all the fine sand has been eliminated. The material passing through is to be added to the beaker before the fine sand separation above. The residue remaining on the sieve consists of the fine gravel and the coarse sand. Separate the fine gravel by means of a sieve with round holes 1 mm. in diameter, and transfer each fraction to weighed silica crucibles, ignite over Meker burners, cool in a desiccator, and weigh.

% coarse sand = weight of coarse sand $\times$ 4.

% fine gravel = weight of fine gravel $\times$ 4.

For one or two soils of each particular type encountered in a soil survey it may be desirable to determine a fraction finer than the clay fraction. To do this, instead of syphoning the liquid off after the determination of the clay, replace the cylinder in the shaking machine for twenty minutes, then remove the cap (without rinsing at this stage), and set the cylinder aside for ten minutes to allow all of the fine sand to collect on the bottom. Then syphon about a litre of the supernatant liquid into a shorter sedimentation cylinder (30 cm. high and 6.5 cm. diam.), and place this latter aside to sediment in a room as free as possible from temperature changes. After ten days pipette off a 20 ml. sample from a depth of 8.6 cm. below the surface. The ignited weight of this sample multiplied by 250 gives the percentage of material having a settling velocity of less than .00001 cm. per sec. (i.e., the log. of the settling velocity $= \bar{5}$ or less).

The fine sand is, of course, determined in the usual way, using the residue in the first cylinder, and rinsing any fine sand which may be on the cap of the cylinder.

3. Equipment for Mechanical Analysis.

As some of the apparatus used in this method has been specially selected or designed, it will be described in detail.

(*a*) *Shaking Machine.*—The shaking machine was designed at the Waite Institute in conjunction with the Physics Workshop of the University of Adelaide. It holds ten cylinders, and is driven by an enclosed worm gear from a $\frac{1}{4}$-h.p. electric motor. The cylinders are closed by

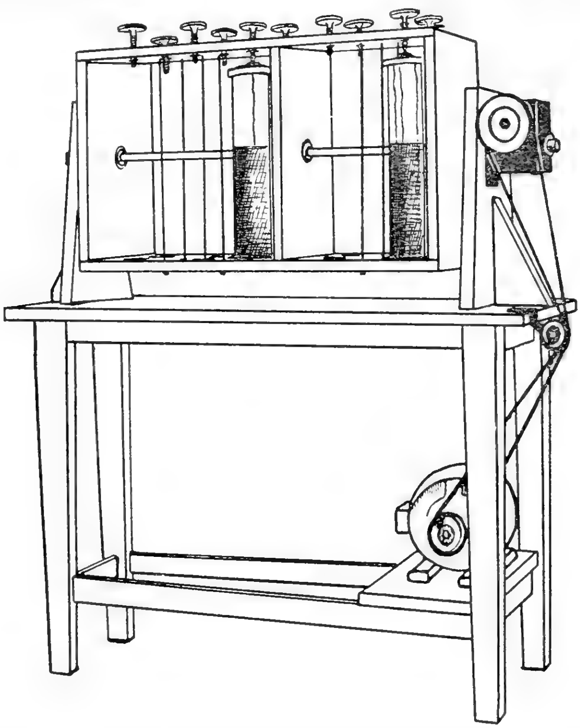

Fig. 4—End over end shaking machine designed to take ten 1,250 ml. cylinders for use in mechanical analysis and soluble salt extraction of soils.

means of brass caps fitted with rubber discs ; the brass caps also serve the purpose of retaining the cylinders in the machine. The machine in its present form is illustrated in Fig. 4. Full specifications and constructional details can be obtained from the Waite Institute.

(*b*) *Sieves.*—These are of brass, $3\frac{1}{2}$ inches in diameter at the top, and at the screen and tapering below this to $2\frac{1}{4}$ inches diameter, so that they fit into the top of the sedimentation cylinders. Standard brass or copper gauze (Institute of Mining and Metallurgy standard 90-mesh gauze) must be used for the screen. A set of ten of these sieves is required.

For the separation of the fine gravel, one or two sieves, 3½ inches in diameter, and fitted with a brass screen having round holes 1 mm. in diameter, are required.

(*c*) *Sedimentation Cylinders.*—These are listed 40 cm. high and 6.5 cm. internal diameter. They are usually ungraduated, but they should be ordered to be graduated to contain 1,250 ml. and the graduation mark etched completely round the cylinder. A set of ten of the above cylinders is required.

Similar cylinders, ungraduated, but 30 cm. high and 6.5 cm. internal diameter, may be employed when a fraction finer than the clay is to be determined.

(*d*) *Pipettes.*—For pipetting the first sample, special long-stemmed pipettes have been designed. The following are the detailed specifications :—

Pipette to deliver 20.00 ml. at 15° C. (Makers guarantee to come within limits of N.P.L. Class B).

Lower stem to be 41 cm. long, and to have a ring etched around it at a distance of 300 mm. from the tip.

Upper stem of the usual dimensions.

Time of delivery (to be etched on each pipette) to be between the limits of 25 and 30 secs. These pipettes are now catalogued by Wood Bros., No. W382.

Ordinary 20 ml. pipettes are used for the second and third samples. A ring is etched around the lower stem at a distance of 12.0 cm. and 8.6 cm. from the tip of the pipette. The time of delivery of these pipettes must also come within the limits of 25 and 30 seconds. Each pipette is numbered so that it is always used in the correspondingly numbered cylinder.

One set of ten long-stemmed pipettes and two sets, each of ten ordinary pipettes, are required.

(*e*) *Suction Regulating Device.*—This device is shown diagrammatically in Fig. 5. It enables a filter pump to be used for filling the pipettes. The pump is fully turned on, so that it will continue to work even if the water pressure nearly fails, and connected to the top of tube A, 4 to 4.5 cm. diameter and 130 cm. long, which is filled with water to a depth of about 30–35 cm. above the lower end of tube B. It thus acts as a valve, and should the reduction of pressure exceed this predetermined amount (30–35 cm. of water), air passes in through tube B and maintains constant suction by preventing the vacuum increasing beyond this. Under these conditions, the pipette, connected by a rubber tube to E, can be filled very gently and without disturbing the lower layers of the suspension. If the column of water in A is increased, the pipette fills too rapidly, drawing the suspension from a point below the required depth, and inaccurate results are obtained.

(*f*) *Beakers* (for the fine sand decantation).—The 500 ml. tall-shaped pyrex beaker is the most suitable. A mark 10 cm. above the bottom of the beaker should be etched on the side by means of hydrofluoric acid. A set of ten beakers is required.

(*g*) *Buchner Funnels*.—These are 12.5 cm. external diameter, and take an 11 cm. filter paper. A set of ten is required.

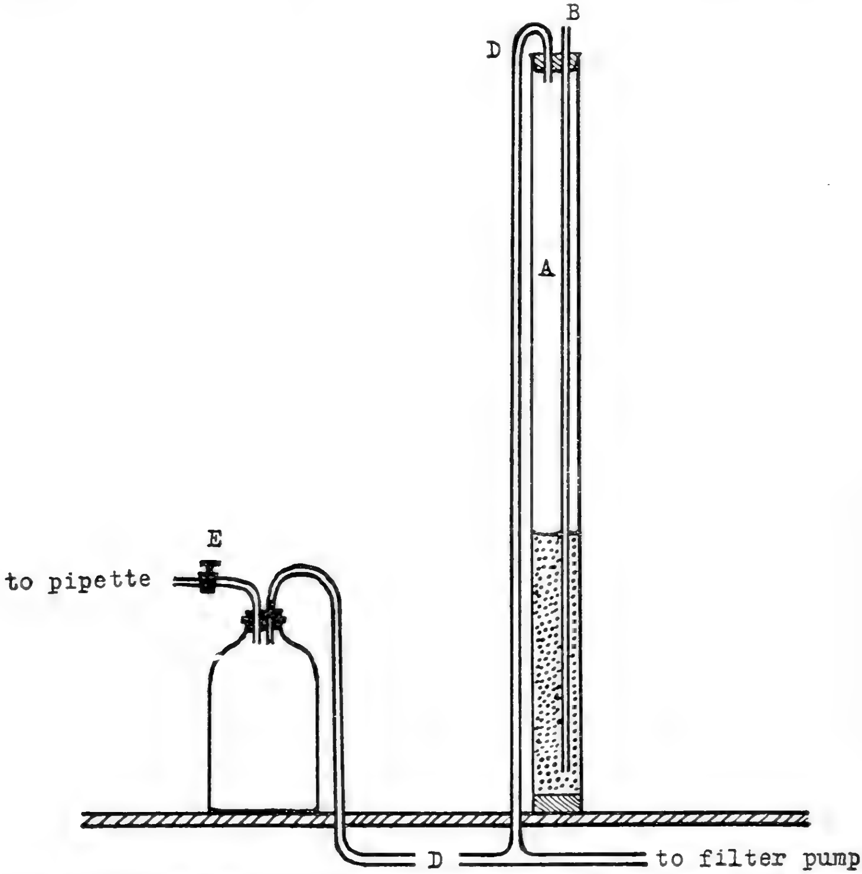

Fig. 5—Suction regulating device for maintaining a constant gentle suction for use with pipette.

IV.—CHEMICAL ANALYSIS.

1. Soil Carbonates.

The method in use is based upon that of H. B. Hutchinson and K. MacLennan.* The apparatus is illustrated in Fig. 6.†

Weigh out 0.5 to 25g. of the soil, depending on the amount of carbonates present, and transfer it to the flask B. Pipette 50 ml. of N/10

* Hutchinson, H. B., and MacLennan K. *Journ. Agric. Sci.*, 6, pp. 323–327 (1914).
† The tube of the separating funnel A should project almost to the bottom of flask B.

sodium hydroxide, carbonate free, into the flask D, and add four or five drops of a 1 per cent. alcoholic solution of phenolphthalein. Place both rubber stoppers in position, close the stopcock of the separating funnel A, and open the stopcock E. Connect the latter to a good filter pump, and evacuate until the pressure is 70 cm. or more below atmospheric. Then close the stopcock E, disconnect from the pump, and add about 50 ml. of 2 per cent. hydrochloric acid (concentrated hydrochloric acid diluted with carbon dioxide free distilled water) to the separating funnel A. Open the stopcock very gradually and allow the acid to enter the flask and react with the soil, avoiding too vigorous a reaction. When nearly all the acid has been drawn in, close the

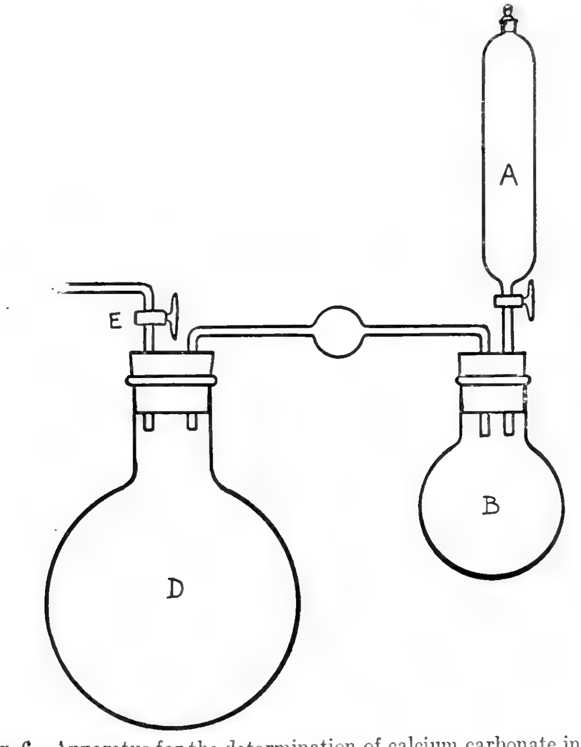

Fig. 6—Apparatus for the determination of calcium carbonate in soil.

stopcock. After a few minutes gently shake the flask to ensure complete decomposition of all carbonates. Repeat this shaking four times in all during twenty minutes. Then connect the top of the separating funnel to a gas washing cylinder, containing 40 per cent. caustic potash, and slowly draw air in through B until the vacuum is destroyed. This should occupy about ten minutes. Shake the flasks at five-minute intervals for a further twenty minutes to ensure the complete absorption of all the carbon dioxide. Then remove the flask D and rinse the stopper into it, using distilled water previously boiled and cooled. Add about 5 ml. of a solution of barium chloride (150 g. of $BaCl_2.2H_2O$ per litre) to the contents of the flask, and titrate with tenth normal hydrochloric acid until neutral to phenolphthalein.

Make a blank determination, using all the reagents but without any soil in the flask B.

Then the percentage of carbonate present in the soil (expressed as $CaCO_3$)=

$$\frac{\text{(Blank titration—Actual titration)}}{\text{Weight of soil used}} \times .005 \times 100.$$

The use of Collins's calcimeter as mentioned by E. J. Russell* is also to be recommended. It is particularly useful for occasional soil samples.

2. Mineral Substances brought into Solution by Digestion with Concentrated Hydrochloric Acid.

Digestion with acid.†—Place 50 grms. of the air-dry soil in a 500 ml. pyrex Erlenmeyer flask and add 175 ml. of concentrated hydrochloric acid. Place a small glass funnel in the neck to act as a condenser. Boil for a few minutes over a flame so as to reduce the strength of the hydrochloric acid to the constant boiling strength. Then digest in a boiling water bath for 48 hours.

Filter through a Buchner funnel, and wash with hot water containing 50 ml. of concentrated hydrochloric acid per litre. (This acid is necessary to prevent the hydrolysis of ferric and aluminium salts in hot dilute solutions.) The washing should be continued until the filtrate amounts to nearly 800 ml. Transfer the filtrate to a litre measuring flask, and when cold dilute to the mark and mix well.

Use this solution for the determination of—

(i) Fe_2O_3 and TiO_2	75 ml. to 50 ml. portions
(ii) Mn_3O_4	100 ml. portions.
(iii) $Fe_2O_3+Al_2O_3$, CaO and MgO ..	25 ml. to 50 ml., according to the relative amounts of iron and calcium present.
(iv) K_2O and P_2O_5	100 ml. portions.

(i) Ferric Oxide and Titanium Dioxide.

(*a*) *Ferric Oxide*, Fe_2O_3.—Evaporate 75–50 ml. of the hydrochloric acid extract in a silica basin on the water bath until the volume is reduced to about 25 ml. Cover with a clock glass, and then add 20 ml. of pure fuming nitric acid. (This latter should be diluted with a very little water to prevent too vigorous a reaction if necessary.) Digest for twenty minutes to half an hour, and then remove the clock glass and rinse it into the basin. Add 15–20 ml. (not more) of dilute sulphuric acid (1+1), and continue the evaporation on the bath. After about one hour transfer to a sand bath, and cautiously evaporate until dense fumes of sulphuric acid have been produced for five minutes. If any insoluble matter such as calcium sulphate separates, the basin should be supported just above the sand bath by means of a triangle. This prevents any loss of liquid by bumping which would otherwise occur.

When the contents of the basin have cooled, add about 60–80 ml. of water, and warm, conveniently on the water bath, until as much as possible is in solution. If a large quantity of calcium sulphate is present it will not be completely soluble, but this does not matter. Transfer to a 250 ml. Erlenmeyer flask, washing the basin thoroughly with hot water. Then dilute the liquid in the flask to 150 to 200 ml.

* Russell, E. J. Soil Conditions and Plant Growth, p. 456.
† Official British digestion as given in A. D. Hall, The Soil, 3rd edition 1920), p. 165.

Pass hydrogen sulphide gas into the cold solution for 7–10 minutes. Disconnect from the gas generator and heat until nearly boiling. Test for the presence of any ferric salt by removing two or three drops of the solution and adding them to a solution of potassium thiocyanate contained in a watch glass or white porcelain dish. If it is completely reduced, as indicated by no red colour being produced, the flask is again connected to the hydrogen sulphide generator and the gas bubbled in slowly, the flask being surrounded with cold water. Continue passing the gas until nearly cold. Should the reduction not have been complete, as may occasionally be the case, the hydrogen sulphide is passed into the hot liquid until a second test shows the absence of any ferric salt ; then cool as above, continuing to pass the gas until cold.

Filter through an 11 cm. Whatman No. 44 filter paper into a 500 ml. Erlenmeyer flask, keeping the filter paper full, to avoid any oxidation. Wash the flask and filter paper six times with water containing hydrogen sulphide. Frequently the filtrate becomes opalescent due to finely divided sulphur, but this will not matter as it will be completely oxidized in the subsequent boiling. Again test the filtrate for any ferric salt. If any should have become oxidized during the filtration, the solution must be warmed, treated with hydrogen sulphide until reduced, and then cooled as before. It is unnecessary to filter the liquid again.

Carbon dioxide from a gas cylinder (freed from any possible traces of hydrogen sulphide by bubbling through a solution of copper sulphate and then water) is introduced into the flask, and the latter raised to boiling. Continue to boil for about fifteen minutes, the carbon dioxide still being passed in. Boiling must be continued for some time after the elimination of all hydrogen sulphide, but the liquid must not be concentrated to more than half its original volume. Cool, by placing the flask in a dish of cold water, the stream of carbon dioxide not being interrupted until quite cold. Then rinse the tube into the flask with cold distilled water (previously boiled), and titrate with freshly-standardized N/10 potassium permanganate until the pink blush just persists. The end point should be quite sharp, and the colour should remain for at least a minute. The potassium permanganate should be standardized against pure sodium oxalate.

$$1 \text{ ml. of } N/10\ KMnO_4 = .0080 \text{ grm. } Fe_2O_3.$$

Reserve the liquid after the titration, for the determination of titanium.

(*b*) *Titanium Dioxide*, TiO_2.—To the liquid in the flask, after the titration with potassium permanganate, add 10 ml. of concentrated sulphuric acid, and concentrate by boiling until its volume is about 50 ml. Two or three pieces of broken glass or silica should be added to promote even boiling. Then transfer to a 100 ml. measuring flask,

NOTES.—Hydrogen sulphide incompletely reduces the solution in the cold even when passed for one hour. Ease of reduction depends largely on the amount of free sulphuric acid present. Enough should be present to prevent the hydrolysis of any TiO_2. 15 ml. of (1+1) sulphuric acid gives satisfactory results. This amount should not be exceeded, as excessive amounts greatly retard the rate of reduction.

When desired, Fe_2O_3 can be determined directly in the ignited precipitate of $Fe_2O_3 + Al_2O_3$ secured under Section iii. It is digested in a silica basin, under a clock glass, with 20 ml. of concentrated hydrochloric acid. The digestion is carried out on the water bath for one hour. 15–20 ml. of dilute sulphuric acid (1+1) are added, and then evaporated cautiously on the sand bath until dense fumes are produced. All the ferric oxide will now be in solution if sufficient macerated filter paper was added previously. If it is not all in solution, cool and dilute, add more hydrochloric acid and heat till fuming again. When quite free of hydrochloric acid, dilute and reduce with hydrogen sulphide as before. If titanium is present in sufficient quantity, it can also be determined, as it is completely dissolved by the above digestion.

rinsing the Erlenmeyer well with hot water. When cold add 5–10 ml. of pure hydrogen peroxide (20 vols.) and dilute to the mark. Mix well, not by shaking, but by inverting the closely stoppered flask several times. Then compare the colour produced, in a suitable colorimeter, with that developed by a known amount of a standard solution of titanium sulphate in another 100 ml. flask. Take the average of eight consecutive colorimeter readings.

The amount of TiO_2 in 100 ml. of the test solution=

$$\frac{\text{Depth of titanium standard solution}}{\text{Depth of titanium test solution.}} \times \begin{array}{c}\text{Amount of } TiO_2 \text{ per 100 ml. of} \\ \text{standard colour solution.}\end{array}$$

A correction for the colour due to ferric sulphate may be made by subtracting 0.01 per cent. from the percentage of TiO_2 found for every 5 per cent. of Fe_2O_3 present.

NOTES.—When much calcium sulphate or other insoluble matter is present in the test solution, it is necessary to clear some of the solution for the colour comparison by one of the following methods :—

(*a*) Centrifuging, which gives the most satisfactory results.
(*b*) Allowing to settle in a beaker and decanting.
(*c*) Filtering through a dry No. 44 filter paper, the first runnings being rejected.

Preparation of Standard Titanium Sulphate.—About 2 grams. of the purest titanium dioxide are dissolved in 10 ml. of concentrated sulphuric acid, together with sufficient hydrofluoric acid, in a platinum basin. Evaporate to fuming five times successively, adding about 10 ml. of dilute sulphuric acid (1+1) each time. When all the hydrofluoric acid has been expelled, take up in 15 ml. of sulphuric acid and 60–80 ml. of water and filter into a 2-litre measuring flask. Add 150 ml. of concentrated sulphuric acid, cool, and dilute to the graduated mark. Transfer to a tightly-stoppered reagent bottle. The actual strength of the standard solution is then determined by precipitating duplicate 50 ml. portions with ammonia, filtering, washing, and igniting as TiO_2.

This standard solution should not be poured out of the stock bottle, but the required amounts should be removed by means of dry pipettes, transferred to 100 ml. measuring flasks, 10 ml. of sulphuric acid added, diluted, cooled, hydrogen peroxide added, and then the volume adjusted to the mark.

(ii) Manganese Oxide, Mn_3O_4.

Evaporate 100 ml. of the hydrochloric acid extract nearly to dryness in a silica basin on the water bath. Cover with a clock glass and add 15 ml. of fuming nitric acid. Digest on the bath for about twenty minutes, and then remove the clock glass and rinse it into the basin. Then add 40 ml. of dilute sulphuric acid (1+1) and leave on the briskly-boiling bath for about one hour. Transfer to a sand bath and continue the evaporation cautiously until fumes of sulphuric acid are just produced, and all the chlorine is eliminated.

From this point two methods are available for oxidizing the manganese to potassium permanganate, namely, oxidation with (*a*) potassium periodate or (*b*) ammonium persulphate in the presence of a silver salt. The former method is to be preferred for several reasons.

A silver salt is necessary as a catalyst when ammonium persulphate is used, and must be present in sufficient quantity, but too large an excess is to be avoided. 3 ml. of a 1 per cent. solution of silver nitrate should be added for every milligram of manganese expected. Sometimes the colour developed by this oxidation is more of a rose colour than that of permanganate. When such is the case it may be necessary to allow the solutions to stand for from one to three days before a good colour match can be obtained with the standard. Standing for too long should be avoided, owing to the decomposition of dilute solutions of potassium permanganate. The colour developed by the periodate oxidation is the true colour of permanganate, and the solutions are quite stable for long periods, in the presence of a small excess of potassium periodate.

(*a*) *Oxidation by means of potassium periodate.**—When the contents of the silica basin are cold, add 3–4 ml. of nitric acid and 30–50 ml. of water. Add 0.3 to 0.5 grm. of potassium periodate, and bring the contents of the dish to a boil, stirring to prevent bumping. Keep just boiling for one minute after the development of the permanganate colour. When sufficiently cool transfer the contents of the dish to a volumetric flask of suitable size (50 ml. to 250 ml. according to the amount of manganese present), and wash the dish thoroughly with small portions of hot water so that the total volume never exceeds about 90 ml. Place the flask in a boiling water bath for 10–15 minutes. Then remove and allow to cool. When quite cold dilute to the mark and mix the contents well, not by shaking but by inverting the closely-stoppered flask several times.

Prepare a standard manganese colour solution by pipetting an appropriate amount of the standard manganous sulphate into a volumetric flask, adding 15 ml. of concentrated sulphuric acid, 3–4 ml. of nitric acid and diluting to about 60–70 ml. Add 0.3–0.5 gms. of potassium periodate, and heat in a boiling water bath for fifteen minutes, and then remove. When cold, dilute to the mark and mix well.

Compare the intensity of colour of the test solution with that of the standard solution by means of a colorimeter. For good colour comparisons the test solution should not be more than 40 per cent. stronger or 25 per cent. less than the strength of the standard colour solution.

(*b*) *Oxidation by means of ammonium persulphate in the presence of a silver salt.*—When the contents of the silica basin are cold, add 25–30 ml. of water and sufficient 1 per cent. silver nitrate solution (see above). Warm until as much as possible is dissolved. Transfer to a 100 ml. (200 ml. or 250 ml.) measuring flask, and wash the basin thoroughly into it with hot water.

To the contents of the flask add 10 ml. of a freshly-prepared 20 per cent. solution of ammonium persulphate (dissolved in cold water). Heat in a water bath at about 80° for 5–10 minutes until the proper colour is developed. Then cool by surrounding the flask with cold water. Leave overnight or till ready to make the colour comparison. When ready, dilute to the mark with water and mix well by inverting the closely-stoppered flask several times.

* Willard, H. H., and Greathouse, L. H. *Jour. Amer. Chem. Soc.*, 39, pp. 2366–2377 (1917).

Compare the colour developed in the test solution with that developed when a known amount of standard manganese sulphate solution is acidified with 10 ml. of concentrated sulphuric acid and oxidized, under the same conditions as before, with silver nitrate and ammonium persulphate.

Standard Manganous Sulphate Solution.—This should contain the equivalent of 1 mg. of Mn_3O_4 per 10 ml.

Dissolve 0.4144 grm. of the purest, dry, potassium permanganate in 500 ml. of water in a 2,000 ml. measuring flask. After standing for a day or two add 40 ml. of concentrated sulphuric acid and reduce the permanganate by the very cautious addition of an aqueous solution of pure sulphur dioxide, until the manganese solution just becomes colourless. Oxidize the excess of sulphurous acid by the addition of a little nitric acid. When cool, dilute to the 2,000 ml. graduation and mix well. Store this standard solution in a tightly stoppered bottle. It should never be poured from its stock bottle, but the appropriate amounts should be removed by means of dry pipettes when making up the standard colour solutions.

When much insoluble matter (silica or calcium sulphate) is present in the test solution, it must be removed before attempting the colour comparison. Centrifuging sufficient liquid for the colorimeter, for three or four minutes, is the most satisfactory method of obtaining a clear solution, but it can sometimes be clarified by allowing the test solution to stand in a tall-shaped beaker and decanting the supernatant liquid.

From the colorimeter readings calculate the amount of manganese (expressed as Mn_3O_4) present in the test solution.

Concentration of Mn_3O_4 in the test solution=

$$\frac{\text{Depth of standard solution}}{\text{Depth of test solution}} \times \text{Concentration of } Mn_3O_4 \text{ in the standard colour solution.}$$

(iii) Iron, Aluminium, Calcium, and Magnesium.

(*a*) *Elimination of Silica.*—Pipette 25 ml. to 50 ml. (depending on the relative amounts of iron and calcium present) into a silica basin, and evaporate to dryness on the water bath. Cool for a few moments and then add 15 ml. of fuming nitric acid (s.g. 1.5), cover with a clock glass and replace on the water bath. After fifteen minutes' digestion, remove the clock glass, rinse it into the basin, evaporate the contents to dryness, and leave on the bath for a further half to one hour to render the silica insoluble.

Take up in 30 ml. of dilute hydrochloric acid (1+9). Warm for a few minutes until all the soluble matter is in solution. Filter through a 9 cm. Whatman No. 44 filter paper into a 400 ml. beaker. Wash twice with cold water and then four times with hot water containing 50 ml. of hydrochloric acid per litre. Complete the washing with hot water alone. The filter paper containing the SiO_2 is rejected. Alternatively, filtration may be effected by using a small Buchner funnel, fitted with a 4.25 cm. Whatman No. 50 filter paper, and washing as before.

(*b*) *Iron and Alumina*, $Fe_2O_3+Al_2O_3+P_2O_5+TiO_2$. *Basic Acetate Separation.*—Concentrate the filtrate and washings from the silica separation on the water bath until the volume is reduced to about 50 ml.

When quite cold, add a freshly-prepared cold 20 per cent. solution of sodium carbonate, the beaker being covered to prevent loss by spray. Add the sodium carbonate gradually at first, and finally drop by drop, until the liquid in the beaker has just darkened in colour, but no precipitate has formed. (A bent funnel can be used for the addition of the sodium carbonate.) If, after the addition of the last drop of sodium carbonate and after rinsing the cover glass and the sides of the beaker, there is a precipitate, then one, or if need be, two drops of dilute hydrochloric acid (1+3) are to be added. If this fails to clear the solution, the precipitate must be re-dissolved by the smallest possible amount of dilute acid, and diluted sodium carbonate again added more carefully drop by drop from a tube, until the liquid has just darkened in colour.

The volume at this stage should not exceed 75–100 ml. Add 6 to 8 ml. of 20 per cent. sodium acetate solution, and then fill the beaker to about 350 ml. to 375 ml. with hot water. Heat to boiling while still covered with the clock-glass, and boil gently for three minutes, but not longer. Allow to stand a few minutes until most of the precipitate has settled, and then filter through a suitable size (12½ cm. or 11 cm.) Whatman No. 41 filter paper. Collect the filtrate in a 600-800 ml. beaker. Wash the original beaker and precipitate three or four times with hot 0.2 per cent. sodium acetate.

Transfer the filter and precipitate to the original beaker. Add 25 ml. of warm dilute nitric acid (1+1), pouring it around the sides of the beaker and stirring rod to dissolve the precipitate. Add 75 ml. of water and a little macerated filter paper and heat until all the iron and aluminium is dissolved. When nearly boiling add dilute ammonia (1+1) in slight excess.

Raise to boiling and then remove from the flame. After standing a few minutes until most of the precipitate has settled, filter through a 12½ cm. No. 41 filter paper. Wash well with hot water, collecting the filtrate in the same beaker as that containing the filtrate from the first precipitation.

Transfer the filter and precipitate to a weighed silica crucible, and along with the trace of Fe_2O_3 and Al_2O_3 recovered below, dry, ignite in the muffle, and weigh as $Fe_2O_3+Al_2O_3+TiO_2+P_2O_5$. When it is necessary to determine Fe_2O_3 in this precipitate, see note under section (i.) (alternative method for Fe_2O_3).

Concentrate the liquid in the 600–800 ml. beaker, overnight, on the water bath, to about 50–100 ml. Then make it just ammoniacal, boil, and filter through a 9 cm. No. 41 filter paper to remove any $Al(OH)_3$. Wash the beaker and filter well with hot water, and collect the filtrate in a 400 ml. beaker. Add the filter and precipitate to the crucible containing the main portion of the iron and aluminium precipitate (above) and ignite.

(c) *Elimination of Manganese.*—Having removed the last traces of iron and aluminium as above, concentrate the filtrate and washings on the water bath until the volume is about 50 ml. Cool in a dish of water. When quite cold add sufficient bromine water (generally 30-50 ml.) to colour the liquid fairly strongly, and then add a very little dilute ammonia (1+9) until just alkaline to litmus. Cover the beaker with a clock glass, and boil for a short time (three minutes). Again cool in water and add bromine water and ammonia as before, and boil again to complete the precipitation of the manganese. Make just acid with dilute acetic acid (20 per cent.), and filter while hot through an 11 cm. No. 44 filter paper. Wash well with hot water and collect the filtrate in a 600 ml. beaker. The filter paper containing the precipitated manganese is rejected. (This precipitate is not pure and cannot be weighed directly for the Mn_3O_4. determination. It usually only amounts to 1 to 3 mgs. in weight.)

(*d*) *Calcium Oxide*, CaO.—Boil the filtrate from the manganese separation, which should not exceed 300–350 ml., and add 10 to 15 ml. of hot 10 per cent. ammonium oxalate. Then add sufficient ammonia (40 ml. of 1+1) to make the liquid quite alkaline. Allow the precipitated calcium oxalate to stand overnight.

Filter through an 11 cm. No. 44 filter paper and collect the filtrate in a second 600 ml. beaker. Wash three times, by decantation, with hot water. Evaporate the filtrate to small bulk on the water bath.

Dissolve the precipitated calcium oxalate by pouring 25 ml. and then 10 ml. of warm dilute hydrochloric acid (1+4) on to the filter and collecting the filtrate in the beaker used for precipitation, washing down its sides. Then wash the filter with two lots of hot 5 per cent. hydrochloric acid and finally hot water alone. Add 2–3 ml. of saturated ammonium oxalate solution to the filtrate and raise to boiling. Precipitate by adding an excess of dilute ammonia (1+1), allow to stand overnight, and filter through the same filter as used previously. Collect the filtrate in the beaker containing the first filtrate, which by now has been concentrated nearly to dryness. Wash the beaker and filter well with hot water. Reserve the filtrate for the magnesium determination.

Pierce the filter paper with the stirring rod, and wash the calcium oxalate into the beaker used for the precipitation. Then wash the filter paper alternately with warm dilute sulphuric acid (1+4), made just pink with potassium permanganate, and warm water until all the oxalic acid is in solution. (Use three lots of the acid in all.) Warm the solution to about 70° and titrate with N/10 potassium permanganate. Finally, add the filter paper, stir, and see that the pink colour is not discharged.

$$1 \text{ ml. of N/10 } KMnO_4 = .0028 \text{ grm. CaO.}$$

(*e*) *Magnesium Oxide*, MgO.—When the filtrate from the calcium reprecipitation is quite cold, add 50 ml. of 95 per cent. alcohol and 30 ml. of 10 per cent. sodium phosphate solution. After a quarter of an hour add 30–50 ml. of concentrated ammonia and allow to stand overnight. Filter through an 11 cm. No. 44 filter paper, and wash two or three times with dilute ammonia (1+9). The filtrate is discarded.

The precipitated magnesium ammonium phosphate is then dissolved by pouring 15 ml. and 10 ml. of warm dilute nitric acid (1+4) through the filter, the filtrate being collected in the beaker in which the precipitation was made. The filter is then well washed with warm water. When cold, add a fews drops of sodium phosphate solution, 25 ml. of alcohol, and 40 to 50 ml. of ammonia to reprecipitate the magnesium ammonium phosphate. Leave overnight and then filter through a 9 cm. No. 44 filter paper (or the same paper as used previously may be used again). Wash with dilute ammonia water (1+9). Transfer the filter and precipitate to a weighed silica crucible, ignite in the muffle at a bright red heat, and weigh as $Mg_2P_2O_7$.

Weight of precipitate × .3621 = wt. of MgO.

NOTES.—When much silica is present it sometimes tends to pass through the filter paper. When such is the case, the addition of a little macerated filter paper, and washing with water containing dilute hydrochloric acid, will help to retain it. If some of the silica still passes through, a second evaporation will be necessary.

For the basic acetate separation sodium carbonate and sodium acetate should be used instead of ammonium carbonate and ammonium acetate, as sometimes recommended. Much better separation of magnesium is effected in the absence of ammonium salts at this stage.

The use of macerated filter paper in the reprecipitation of the iron and alumina leaves the precipitate in such a finely-divided condition after ignition that it is easily and completely soluble in concentrated hydrochloric acid. It also improves the filtration.

The macerated filter paper is prepared as follows:—Several 11 cm. Whatman No. 44 filter papers are torn in pieces, placed in a 400 ml. beaker, and treated with sufficient concentrated hydrochloric acid to thoroughly moisten them. Allow the acid to react for three minutes, but not longer, and then gradually fill the beaker with water, stirring vigorously to complete the disintegration. Filter through a uchner funnel and wash until free of acid. Mix with water to make a thin cream, and preserve in a wide-mouth stoppered reagent bottle.

(iv) Potash and Phosphoric Acid.

(*a*) *Potash*, K_2O.*—To 100 ml. (equivalent to 5 grms. soil) of the hydrochloric acid extract, add sufficient of a 2 per cent. solution of $BaCl_2 . 2H_2O$ to precipitate all the sulphate (generally 3–5 ml. for ordinary soils), and also if the soil did not effervesce when treated with hydrochloric acid, add 5 ml. of a 4 per cent. solution of $CaCO_3$ dissolved in a slight excess of hydrochloric acid. Evaporate to dryness in a silica basin on the water bath.

Transfer to an air oven at about 100° and gradually raise the temperature to 120°–140° till quite dry. Then gently heat over a large burner until all the ammonium salts have been removed and all the iron salts rendered insoluble. The dish must not be allowed to become more than a very dull red, otherwise potassium may be lost by volatilization.

When cool, add 10–15 ml. of hot water and break up the lumps in the basin with a glass stirring rod. Filter through a 9 cm. Whatman No. 44 filter paper into a pyrex basin of 100–150 ml. capacity. Wash the dish and filter with several small portions of hot water until all the potash has been extracted and the filtrate amounts to about 100 ml. Reserve the filter and residue for the phosphoric acid determination.

To the filtrate add sufficient 20 per cent. perchloric acid to convert all the chlorides present into perchlorates (say, 1 ml. for each per cent. of CaO, K_2O, and Na_2O, and 1¼ ml. for each per cent. of MgO in the soil. Also allow 1 ml. for the barium chloride added, and if calcium chloride was also added, a further 2 ml.). Evaporate on the water bath. An excess of perchloric acid is denoted by the appearance of dense white

* For the details of the perchlorate method, the following original papers have been consulted:—

(1) R. Leitch Morr s. *Analyst*, 45, pp. 349–368 (1920).
(2) R. Le tch Morris *Analyst*, 48, pp. 250–260 (1923).
(3) H. J. Page, *Journ. Agric. Sci.*, 14, pp. 133–138 (1924).
(4) W. A. Davis, *Journ. Agric. Sci.*, 5, pp. 52–66 (1912).
(5) W. A. Davis *Journ. Chem. Soc.*, 107, p. 1680 (1915).

The method as given in many text-books is quite erroneous, but under the following conditions very accurate results are obtainable.

fumes when the evaporation is nearly completed. The evaporation should be finished on a sand bath until dense white fumes of perchloric acid are evolved.

When the white fumes appear add 10–15 ml. of water to dissolve the perchlorates, and then $1\frac{1}{2}$ ml. of perchloric acid, and continue the evaporation nearly to dryness on the water bath. Finish the evaporation over a sand bath or a heated asbestos plate until dense white fumes have been produced for some time and the liquid just sets to a pasty crystalline mass when cold.

When quite cold add 15 ml. of alcohol acidified with perchloric acid (500 ml. of 95–96 per cent. alcohol + 5 ml. of 20 per cent. perchloric acid). Break up all lumps with the stirring rod and stir well, then allow to settle. When most of the crystals have settled (say after 15–30 minutes, or it may be left overnight, if covered to prevent evaporation), the clear liquid is decanted through a weighed gooch crucible properly charged with asbestos. Then dry the contents of the dish for a few minutes on the water bath, take up in 10–15 ml. of water, add $\frac{1}{4}$ ml. of perchloric acid, and evaporate nearly to dryness on the water bath, so that the mass is just pasty when cold. When quite cold, add 10 ml. of the acidified alcohol, stir well to break up the crystals, and leave for a few minutes. Filter through the same gooch as used previously. Wash by decantation with 5 ml. of the acidified alcohol, and drain the dish and crucible well to remove most of this before adding the next wash liquid. Then transfer the potassium perchlorate crystals from the dish to the crucible, using two lots of about 15 ml. each of 95 per cent. alcohol, which has been saturated with potassium perchlorate. Remove the last traces of the crystals with a feather.

Wash with a further two lots of 15–20 ml. of this wash liquid and drain well. Dry the crucible at 140° for one hour in an air oven, cool in a desiccator, and weigh as $KClO_4$.

$$\% \text{ of } K_2O \text{ in soil} = \text{weight of ppt.} \times \frac{.3401}{5} \times 100$$

NOTES.—Glass dishes are preferable to silica or porcelain as the last traces of potassium perchlorate are more easily seen in the former.

The removal of all SO_4 is absolutely necessary (R. L. Morris and W. A. Davis).

The perchloric acid used must be reasonably free of chloric acid (H. J. Page).

The alcohol saturated with potassium perchlorate (Davis) is prepared and kept in a winchester, with an excess of pure potassium perchlorate, and will then remain saturated. As the solubility increases rapidly with rise of temperature, it should only be filtered off immediately prior to use. (Filter through a Buchner funnel fitted with two Whatman No. 44 filter papers.)

Potassium perchlorate is slightly soluble in the acidified alcohol used for the first washing, so the quantity of this must be kept down to a minimum.

Some precipitation of potassium perchlorate will occur in the filter flask from the reaction between the saturated alcoholic solution and the acidified alcohol used in the first washing. Hence the necessity of draining the crucible completely between the two washings, to prevent this precipitation occurring within the crucible.

(b) *Phosphoric Acid*, P_2O_5.—(i)* Replace the filter paper, containing the residue after the extraction of the potash with hot water, in the original silica basin, and ignite to remove the filter paper. Add 30 ml. of dilute hydrochloric acid (1+1), and one drop of concentrated sulphuric acid. The latter is necessary to precipitate traces of barium. Cover with a clock glass, and digest on the sand bath for 15–20 minutes. Remove and rinse the cover glass into the basin and evaporate the contents to dryness on the water bath. Continue the heating on the bath for a

* Lunge, G., and Keane, C. A., "Technical Methods of Chemical Analysis," Vol. II., Part 1, pp. 397–400. Jefferis, A. T., and Piper, C. S., *Chem. Eng. and Mining Review*, 17, pp. 154–157 (1925).

further half-hour to render the silica insoluble. Or alternatively heat in an air oven at 110°–120° for a half to one hour. Take up in 5 ml. of concentrated nitric acid and 20–25 ml. of water, warm to dissolve all the soluble salts, and filter through a 9 cm. Whatman No. 44 filter paper, collecting the filtrate in a tall 150 ml. beaker. Wash thoroughly with hot water until the volume of the filtrate amounts to about 120 ml. Place the beaker on the water bath and evaporate the filtrate to dryness. Take up in 30 ml. of the Acid Reagent IV. (see below). Heat the beaker to incipient boiling, remove from the flame and stir for a moment to avoid overheating of the sides of the beaker. With constant stirring add 30 ml. of Lorenz Reagent III. After standing for 2–5 minutes stir well for half a minute, and then place the beaker aside and allow to stand overnight.

After standing, filter through a gooch crucible fitted with a circle of filter paper (Whatman No. 2 or No. 41) cut so that it just covers the holes but does not touch the sides. The gooch and filter paper should have been previously rinsed with acetone, sucked dry at the pump, and placed in a vacuum desiccator (evacuated to 100–200 mm.) for half an hour prior to weighing.

Connect the weighed gooch crucible to a filter pump and moisten the circle of filter paper. Then decant the solution from the beaker into the crucible, finally transferring the bulk of the precipitate. Rinse the beaker twice with 20–25 ml. portions of the ammonium nitrate reagent, using a wash bottle to rinse the precipitate into the crucible. Then clean the sides of the beaker with a rubber-tipped stirring rod and rinse it into the crucible using another two portions, each of 20–25 ml. of the ammonium nitrate. The crucible is to be sucked dry between each addition of the washing liquid. Finally wash three times with acetone, completely filling the crucible once and half-filling it twice, sucking dry between each addition.

Wipe the outside of the crucible and place it in the vacuum desiccator, which must not contain either sulphuric acid or calcium chloride, evacuate as before, and after half an hour weigh. The precipitate contains 3.295 per cent. of P_2O_5.

$$\% \ P_2O_5 \text{ in soil} = \text{weight of precipitate} \times \frac{3.295}{5}$$

When the soil contains less than 4 per cent. of calcium carbonate the determination can be made directly and with equal accuracy by evaporating 100 ml. of the hydrochloric acid extract on the water bath, drying in an air oven at 110°–120°, taking up in 5 ml. of concentrated nitric acid and 20–25 ml. of water, filtering and proceeding exactly as above.

The following reagents are required for the Lorenz method :—

Lorenz Reagent I.—Sulphate-Molybdic Acid.—Dissolve 100 grms. of pure dry ammonium sulphate in 1 litre of nitric acid of S.G. 1.36 at 15° C., in a 2-litre flask. Dissolve 300 grms. of pure dry ammonium molybdate in hot water and transfer to a litre measuring flask, cool the solution to about 20° C., and dilute to the mark. Mix well and pour this solution, in a thin stream, and with constant agitation, into the solution contained in the 2-litre flask. Allow to stand for 48 hours at room temperature, and then filter through a Buchner funnel fitted with a Whatman No. 50 filter paper. Keep in a well-stoppered bottle in a cool, dark place. Under these conditions the solution does not deposit molybdic acid.

Lorenz Reagent III.—Nitric-Sulphuric Acid.—Add 30 ml. of concentrated sulphuric acid to one litre of nitric acid (S.G. 1.20 at 15° C.).

Acid Reagent IV.—This is composed of 960 ml. of Lorenz Reagent III., 24 ml. of concentrated sulphuric acid, and 225 ml. of water.

Ammonium Nitrate Solution.—Make up a 2 per cent. aqueous solution for washing. If the solution is not acid to litmus, add a few drops of nitric acid per litre.

Acetone.—This should be non-alkaline and free from residue. The acetone washings are kept, dehydrated with potassium carbonate, and redistilled.

(ii)* Alternatively, the residue from the leaching out of the potassium may be digested with 50 ml. of 10 per cent. sulphuric acid and filtered. The filtrate is treated with 25 ml. concentrated ammonium nitrate solution and warmed to 55° C. 25 ml. of filtered ammonium molybdate solution, previously warmed to 55° C., is added, and the whole allowed to stand for two hours. The solution is then filtered, and the precipitate washed with 2 per cent. sodium nitrate, till the washings are neutral. Transfer the precipitate and filter papers to the beaker used for the precipitation, add a known volume of standard alkali so that the precipitate completely dissolves, measure the excess by titration, using phenolphthalein as indicator.

1 ml. of N/10 alkali = .0003004 gm. P_2O_5.

Swedish filter paper is to be recommended for this filtration.

3. One per cent. Citric Acid Extract.

(*i*) *Preparation of Extract.*

Add 250 grms. of soil to 25 grms. of citric acid dissolved in 2,500 ml. of water in a large winchester quart. Close with a rubber stopper, and place in the shaking machine and shake for 24 hours. Then allow to stand overnight, and syphon off as much as possible of the supernatant liquid. Filter this through an 11 cm. or 12.5 cm. Buchner funnel charged with asbestos, using a small portion of about 50 ml. to rinse the funnel and flask before filtering the main portion. If an insufficient volume of filtrate is obtained in this way, add some of the residue in the winchester to the filter and continue to collect the filtrate.

Transfer duplicate portions of the filtrate, each of 750 ml., to silica basins and evaporate to dryness on the water bath. When dry, heat carefully to destroy organic matter, avoiding any loss of potash by overheating. When cold, cover with a clock glass and add 40 ml. of dilute

* J. A. Prescott, *Journ. Agric. Science*, 6, pp. 111 (1914). For a further discussion of this method see M. B. Richards and W. Godden, *Analyst*, 49, pp. 565–572 (1924).

hydrochloric acid (1 + 1) and heat on the water bath for twenty minutes to completely dissolve all the potash and phosphoric acid. Remove and rinse the clock glass and evaporate the contents of the basin to dryness. Continue heating on the water bath for half an hour to render most of the silica insoluble. Then add 100 ml. of dilute hydrochloric acid (1 + 5) and warm on the bath for 15–20 minutes to effect solution. Filter through an 11 cm. Whatman No. 41 filter paper, collecting the filtrate in a 200 ml. silica basin. Wash thoroughly with hot 5 per cent. hydrochloric acid, breaking up the lumps of charred organic matter in the first basin with a pestle before transferring them to the filter.

(*ii*) *Determination of Potash and Phosphoric Acid.*

(*a*) *Potash,* K_2O.—To the filtrate from the above add sufficient of a 2 per cent. solution of barium chloride to completely precipitate all the sulphates present. 5 ml. is usually sufficient, but more must be added in some cases as it is necessary to remove all sulphate before proceeding to the perchlorate separation. Evaporate the contents of the 200 ml. basin to dryness on the water bath, and if necessary complete the drying in an air oven at 110°–120° for one hour. Then heat carefully over a large burner until all ammonium salts have been expelled and all the iron rendered insoluble. In order to avoid any possible loss of potassium by volatilization, the dish must not be heated above a very dull red heat.

When cold add 10–15 ml. of hot water and break up the lumps in the basin with a glass stirring rod. Filter through a 9 cm. Whatman No. 44 filter paper into a pyrex basin of 100–150 ml. capacity. Wash the dish and filter with several small portions of hot water until all the potash has been extracted and the filtrate amounts to about 100 ml. Reserve the filter and residue for the phosphoric acid determination.

To the filtrate add sufficient 20 per cent. perchloric acid to convert all the chlorides present into perchlorates. (Generally, 10–15 ml. of perchloric acid is required, but more may be necessary. An excess must be present, and is denoted by the production of dense white fumes at the end of the evaporation.) Evaporate on the water bath, and finally on the sand bath, until dense fumes of perchloric acid are evolved. Then add 10–15 ml. of water to dissolve the perchlorates and $1\frac{1}{2}$ ml. of perchloric acid, and continue the evaporation nearly to dryness on the water bath. Finish the evaporation over a sand bath or heated asbestos plate until dense white fumes have been produced for some time and the liquid just sets to a pasty crystalline mass when cold. From this point proceed exactly as described on page 29 for the estimation of potassium in the hydrochloric acid extract.

(*b*) *Phosphoric Acid.* P_2O_5.—This is determined in the residue from the potash extraction exactly as described on page. 30 for the determination of phosphoric acid in the hydrochloric acid extract.

4. Methods for the Determination of Replaceable Bases.*

As base exchange is a reversible reaction, complete replacement can only be effected by leaching the soil with a concentrated salt solution and so removing the replaced base from the sphere of action. For soils

* Hissink, D. J., *Intern. Mitt. Bodenkunde,* 12, pp. 104 (1922). Trans. 2nd Commission Int. Soc. Soil Science, B., 181 (1927).

in which calcium carbonate is absent, a normal solution of ammonium chloride is the best reagent to bring about replacement. The bases, sodium, potassium, calcium, magnesium, and also in the case of acid soils, iron, aluminium, and manganese, are then determined in the filtrate. When calcium carbonate or dolomite occurs in the soil, sodium and potassium are to be determined in the ammonium chloride extract, and a second portion of the soil is to be leached, as detailed below, with normal sodium chloride for the determination of calcium and magnesium. Ammonium chloride cannot be used for the latter determinations, owing to the greater solubility of the alkaline earth carbonates therein ; they are not completely insoluble in normal sodium chloride, however, and a correction has to be applied for the amount dissolved by the reagent as distinct from that replaced. At the present time sodium chloride is the best solution available. When magnesium carbonate occurs in the soil (a rare occurrence), there is no satisfactory method for determining either replaceable calcium or magnesium.

When appreciable quantities of sodium chloride or other water soluble salts are present in the soil, they should be removed by leaching with 40 per cent. alcohol until the filtrate is free of chlorine, before commencing the determination of the replaceable bases. If much gypsum is present it may be necessary to wash with water, as well as alcohol, until free of sulphate. In this case, however, such leaching might easily result in the complete replacement of all exchangeable bases by calcium.

Methods of Replacement.—The normal sodium chloride used should preferably be prepared from aerated distilled water (i.e., distilled water from which carbon dioxide has been largely removed by means of a current of air drawn through the water by a water pump).

A. For Soils in which Calcium Carbonate is absent.

To 60 g. of the soil in a 400 ml. beaker, add 200 ml. of a normal solution of ammonium chloride. Place in a water bath at 80° and leave there for one hour, stirring at intervals. Place aside and allow to stand over night. Then decant through a 15 cm. Whatman No. 44 filter paper and transfer the soil quantitatively to the filter, using a jet of the ammonium chloride solution. Collect the filtrate in a litre measuring flask. Continue to leach the filter with small quantities of the normal salt solution, allowing it to drain between successive additions, until one litre of filtrate has been collected. Discard the soil and filter paper, and thoroughly mix the contents of the flask.

Determine—

(*a*) potash and soda in duplicate portions of 150–200 ml.

(*b*) iron and alumina, lime and magnesia in duplicate portions of 200 ml.

(*c*) manganese in a portion of 200 to 250 ml.

B. For Soils containing Calcium Carbonate or Dolomite.

(*a*) Treat a 60 g. portion exactly as in *A* above and secure a litre of filtrate. Determine potash and soda in duplicate portions of 200 ml. each of this filtrate. If required, silica is to be determined in another aliquot.

(*b*) To 30 g. of the soil in a 250 ml. beaker, add 150 ml. of a normal solution of sodium chloride. Place in a water bath at 80° for one hour, stirring at intervals. Allow to stand overnight. Then decant through a 15 cm. Whatman No. 44 filter paper into a litre measuring flask, transfer the soil from the beaker to the filter, using a jet of the normal salt solution, and continue the leaching until one litre of filtrate has been collected. Return the filter paper and soil to the beaker and add sufficient normal sodium chloride solution so that, with the amount already saturating the soil and filter, there will be approximately 150 ml. Heat in a water bath at 80°, stirring frequently, and then allow to stand overnight as before. Decant through a second 15 cm. No. 44 filter paper into a second litre measuring flask, transfer the soil to the filter, and continue the leaching until the second litre of filtrate has been collected.

Determine the calcium and magnesium in duplicate portions, each of 400 ml., of both the first and second litres of filtrate.

The first litre of filtrate contains all the calcium and magnesium originally present in the soil in an exchangeable form, together with calcium and magnesium dissolved by the sodium chloride solution from the calcium carbonate or dolomite present. The second litre contains only calcium and magnesium dissolved from their carbonates, and, therefore, the difference in calcium and magnesium content of the first and second litre of the filtrate gives the amount of replaceable calcium and magnesium respectively in the 30 g. of soil used. The method, although not perfect, is the best available at the present time. Particular cases require individual interpretation ; such as, for instance, when only very small amounts of alkaline earth carbonates are present in the original soil, the whole, or more than half, may be dissolved by the first litre of the normal sodium chloride extract so that a true correction for this solubility effect is not obtained by the calcium and magnesium content of the second litre.

Determination of the Bases.

(*a*) *Sodium and Potassium.*

Pipette 150–200 ml. of the N/1 ammonium chloride extract of the soil into a 200 ml. silica basin. Add 3 ml. of a 2 per cent. solution of $BaCl_2, 2H_2O$, or more if much SO_4 is present, in order to completely precipitate all sulphates. Evaporate on the water bath until the volume is about 50 ml., cover with a clock glass, and add 25 ml. of concentrated nitric acid. When the vigorous decomposition is over, add a further 10 ml., the dish still being covered. After a time remove the clock glass, rinse into the basin, and continue the evaporation to dryness. Add 5 ml. of nitric acid and again evaporate to dryness.

Take up the residue in about 10–15 ml. of water, add 5 ml. of a saturated solution of barium hydroxide, or sufficient to precipitate all the magnesia present. Warm and filter through a 9 cm. Whatman No. 41 filter paper, collecting the filtrate in a tall 250 ml. beaker. Wash completely with hot water until about 150–180 ml. of filtrate is obtained. Add 2 ml. of ammonia to prevent the formation of soluble calcium bicarbonate, boil, and add .75 g. of ammonium carbonate, freshly dissolved without heating in 20 ml. of water. Cover the beaker and boil for one to two minutes. Allow the bulk of the precipitate to settle, and decant through a 9 cm. Whatman No. 44 filter paper into a 400 ml. silica basin. (A platinum basin must not be used.) Wash well with hot water. Cover the basin and place on the water bath. When the decomposition of the ammonium carbonate has ceased, remove and rinse the cover glass and evaporate to dryness. Moisten the contents of the dish with 3–5 ml. of concentrated hydrochloric acid and 5–10 ml. of water and evaporate to dryness. Gently heat to expel all ammonium salts. Again moisten the salts with 2 ml. of hydrochloric acid and 5 ml. of water, and evaporate to dryness. Repeat this evaporation a third time to completely convert all nitrates to chlorides. Take up in 10 ml. of water, rock the dish to dissolve all the salts, and add 5 or 6 drops of the ammonium carbonate solution, and one drop of saturated ammonium oxalate solution. Evaporate to dryness to remove the last traces of calcium.

Dissolve in 3 or 4 ml. of water, and filter carefully through a 7 cm. Whatman No. 44 filter paper, collecting the filtrate in a weighed platinum basin. Wash completely with small portions of hot water. Add one or two drops of hydrochloric acid to the filtrate and evaporate to dryness on the water bath. Very cautiously heat over a bunsen burner, avoiding loss by decrepitation, until the last traces of ammonium salts have been removed. The dish must not be overheated, as some of the alkali chlorides may be volatilized. Cool in a desiccator and weigh as $NaCl+KCl$.

Dissolve the weighed residue of mixed chlorides in 15–20 ml. of water, and add 1 ml. of perchloric acid (S.G. 1.12) for each decigram of $NaCl+KCl$ present. Evaporate on a water bath and finally on a sand bath until dense white fumes of perchloric acid are given off. Add 10 ml. of water and a further ml. of perchloric acid and again evaporate until dense fumes are evolved, and the crystalline mass is just pasty when cold. When quite cold add 15 ml. of 96 per cent. alcohol containing .2 per cent. of perchloric acid. Break up all the lumps with the stirring rod and stir well. Allow the dish to stand for half an hour. When most of the crystals have settled, decant as much as possible of the clear liquid through a dried and weighed gooch crucible, properly charged with asbestos and connected to a filter pump. Place the platinum basin on the top of the water bath to eliminate the alcohol, take up in about 10 ml. of water, and add $\frac{1}{4}$ ml. of perchloric acid. Evaporate just to dryness, and when quite cold add 10 ml. of the acidified alcohol, stirring well to break up the crystals. After a few minutes decant through the same gooch crucible as used previously. Wash by decantation with 5 ml. of the acidified alcohol, draining the dish and crucible completely. Then transfer the bulk of the potassium perchlorate to the filter, using a stream of 95 per cent. alcohol, saturated with potassium perchlorate, from a wash bottle. Not more than 30 ml. should be used. Remove the last traces of the precipitate from the sides of the basin with a feather. Finally wash with a further two lots of about 15 ml. each of this wash liquid. Drain the crucible well and dry in an oven at 140° for one hour. Cool in a desiccator and weigh as $KClO_4$.

$$\text{Wt. of } K_2O = \text{wt. of } KClO_4 \times .3401$$
$$\text{Wt. of } KCl = \text{wt. of } KClO_4 \times .5381$$

From the weight of potassium perchlorate, calculate the percentage of K_2O present. Also calculate the weight of KCl and deduct this latter from the weight obtained for NaCl+KCl. The weight of NaCl so obtained × .5303 gives the weight of Na_2O.

As a check, when necessary, potassium can be directly determined by the perchlorate method by the removal of SO_4 by barium chloride, the removal of ammonium salts by repeated evaporations with nitric acid and gentle heating, leaching with hot water, and separation of potassium perchlorate by evaporation (twice) with perchloric acid.

(*b*) *Iron + Aluminium, Calcium, and Magnesium. (In soils free of calcium carbonate.)*

Fe_2O_3 + Al_2O_3.—Pipette 200 ml. of the N/1 ammonium chloride extract into a 250 ml. beaker, boil, and add 10 ml. of dilute ammonia (1+1) to precipitate all the iron and alumina. Filter through a 9 cm. No. 41 Whatman filter paper and wash well with hot water, collecting the filtrate in a 400 ml. beaker.

Ignite the filter and precipitate in a crucible and weigh as Fe_2O_3+ Al_2O_3.

CaO.—Heat the filtrate from the Fe_2O_3+Al_2O_3 separation, to boiling and add 30 ml. of dilute ammonia (1+1) and 15 ml. of hot 10 per cent. ammonium oxalate solution. Keep just at or below boiling point for 5–10 minutes until the precipitate of calcium oxalate has become quite granular. Cover with a clock glass and leave to stand overnight. Filter through an 11 cm. Whatman No. 44 filter paper into a 600 ml. beaker, and wash twice with hot water.

Dissolve the precipitated calcium oxalate by pouring 15 ml. and 7½ ml. of hot dilute hydrochloric acid (1+4) on to the filter, and washing well with hot water, collecting the filtrate in the beaker in which the precipitation was made. Add 3 ml. of a 2 per cent. solution of ammonium oxalate, boil, and add 35 ml. of dilute ammonia (1+1). Keep just boiling as before for five minutes until the precipitate becomes granular. Cover and allow to stand overnight. Filter through the same filter paper as used previously, and wash completely with hot water. The filtrate is collected in the 600 ml. beaker containing the filtrate from the first precipitation. Reserve this for the magnesium determination.

When the precipitated calcium oxalate has been completely washed, replace the 600 ml. beaker with the beaker in which the precipitation was made. Pierce the filter paper with a glass rod and wash as much as possible of the precipitate through, using a stream of warm water. Then wash the filter paper alternately with warm dilute sulphuric acid (1+4), made just pink with two or three drops of standard $KMnO_4$ per 200 ml., and warm water, until all the oxalic acid is removed. Three portions, each about 20 ml., of the acid should be used. Then warm the contents of the beaker to about 70° and titrate with N/10 or N/40 potassium permanganate.

1 ml. of N/10 $KMnO_4$=.0028 g. of CaO.
1 ml. of N/40 $KMnO_4$=.0007 g. of CaO.

MgO.—Evaporate the combined filtrates from the calcium precipitations in a 200 ml. silica basin until the volume is reduced to about 50–60 ml. Cover with a clock glass and add 30 ml. of concentrated nitric acid. When the vigorous reaction is over, add a further 10 ml. of nitric acid, the basin still being covered and left on the water bath. After a further interval rinse the cover into the basin and evaporate to dryness. Add 5 ml. of nitric acid and again evaporate to dryness. Dissolve the residue in hot water and 3–5 ml. of hydrochloric acid. If necessary, to remove traces of silica, filter through a 7 cm. Whatman No. 44 filter paper, collecting the filtrate in a 200 ml. beaker. Wash well with hot water.

When the filtrate is cold add 25 ml. of 95 per cent. alcohol, and 5 ml. of a 10 per cent. sodium phosphate solution. Make just alkaline with dilute ammonia. After fifteen minutes, add 25 ml. of concentrated ammonia to completely precipitate all the magnesium as magnesium ammonium phosphate. Stir well and allow to stand overnight. Filter through a 9 cm. Whatman No. 44 filter paper and wash with dilute ammonia (1+9). Ignite the filter and precipitate, cool and weigh as $Mg_2P_2O_7$.

$$\text{Wt. of ppt.} \times .3621 = \text{wt. of MgO.}$$

(*c*) *Calcium and Magnesium* (*in soils containing calcium carbonate or dolomite*).

CaO.—Transfer 400 ml. of the normal sodium chloride extract into a 600 ml. beaker and add 1 grm. of ammonium chloride to retain the magnesium in solution. Boil and add 35–40 ml. of dilute ammonia (1+1) and 15 ml. of hot 10 per cent. ammonium oxalate solution. Keep just at or below boiling point for 5–10 minutes, and proceed exactly as detailed for CaO in the preceding section.

MgO.—Concentrate the filtrate from the first calcium precipitation by evaporation until its volume is reduced to about 200 ml., and then collect the filtrate from the second calcium precipitation in the same beaker. Add 15 ml. of 10 per cent. sodium phosphate solution and 25 ml. of concentrated ammonia. Stir well and allow to stand overnight. Filter through an 11 cm. Whatman No. 44 filter paper and wash twice with dilute ammonia (1+9). Dissolve the precipitate by pouring 10 ml. +10 ml. of warm dilute nitric acid (1+4) through the filter, the filtrate being collected in the beaker in which the precipitation was made. Wash the filter thoroughly with hot water. When the filtrate is cold add a few drops of sodium phosphate solution, 25 ml. of 95 per cent. alcohol and 40 ml. of concentrated ammonia to reprecipitate the magnesium ammonium phosphate. Allow to stand overnight, and then filter through a 9 cm. Whatman No. 44 filter paper, and wash well with dilute ammonia (1+9). Transfer the filter and precipitate to a weighed silica crucible, ignite in a muffle at a bright red heat, cool, and weigh as $Mg_2P_2O_7$.

$$\text{Weight of precipitate} \times .3621 = \text{weight of MgO.}$$

(*d*) *Manganese.*—Pipette 200 to 250 ml. of the normal ammonium chloride solution into a 200–250 ml. silica basin, and evaporate on the water bath until the volume is reduced to about 50 ml. Cover the basin with a clock glass and add 25 ml. of concentrated nitric acid. When the vigorous reaction is over, add a further 10 ml. of nitric acid. After a time remove and rinse the clock glass and continue the evaporation to dryness. Dissolve the contents of the dish in 10 ml. of concentrated nitric acid, add 50 ml. of dilute sulphuric acid (1—3). and cautiously evaporate on a sand bath or hot plate until the liquid is just fuming. (This eliminates the last traces of hydrochloric acid.) Allow to cool and dilute with 30–50 ml. of water and add 2–3 ml. of concentrated nitric acid. Add 0.3 to 0.5 g. of potassium periodate and bring the contents of the basin to a gentle boil. Keep just boiling for one minute after the development of the permanganate colour. When sufficiently cool transfer the contents to a measuring flask of suitable size (generally 50—100 ml.) and wash the dish thoroughly with small portions of hot water. Place the flask in a boiling water bath for 10–15 minutes. Then remove and allow to cool. When cold. dilute to the graduation mark and mix the contents well by inverting the closely-stoppered flask several times.

If the solution is not clear, centrifuge for 3–5 minutes and transfer the clear solution so obtained to the colorimeter tube.

Prepare a standard solution of potassium permanganate by pipetting 5–20 ml. of standard manganese sulphate (10 ml. = 1 mg. Mn_3O_4) into a 100 ml. measuring flask. adding 30 ml. of water, 15 ml. of concentrated sulphuric acid, and 0.3 g. of potassium periodate. Heat in a boiling water bath for fifteen minutes, and when cold dilute to the graduation mark.

Make a series of colour comparisons between the test solution and one of the above standard potassium permanganate solutions. Make eight successive colour matches and take the average for the depth of liquid in the cell of standard solution. the depth of liquid in the test solution cell being kept constant.

The concentration of Mn_3O_4 in the test solution =

$$\frac{\text{average depth of standard } KMnO_4 \text{ solution}}{\text{depth of test solution}} \times \text{conc. of } Mn_3O_4 \text{ in the standard } KMnO_4 \text{ solution.}$$

5. Water Soluble Salts.

(*a*) *General.*—The determination of water soluble salts is of special importance in a semi-arid country, particularly where irrigation is practised. Of the various constituents, chlorine and nitrate ions are unaffected by the ratio of soil to water, but this is important with respect to carbonate and bicarbonate ions, and has a further bearing on the relative proportions of the cations owing to base exchange phenomena. It is, therefore, necessary to adopt some conventional relationship between the weight of soil and the volume of extraction water and preferably to use distilled water which has been brought into equilibrium by aeration with the carbon dioxide of the atmosphere.

To 200 grms. of air-dried soil are added 1,000 ml. of aerated distilled water in a suitable vessel, and the whole shaken in an end over end shaker for one hour. The cylinders and shaking machine used for mechanical analysis are found to be convenient for this purpose. After allowing the heavier particles to settle for one hour, the suspension is decanted into a cylinder and filtered by suction through a Chamberland candle filter.

The rate of filtration varies with the character of the suspension. With very alkaline soils a complete filtration may take some hours. With very slow filtering suspensions the deposit of clay on the filter may be removed by reversing the pressure in the candle by connecting momentarily to a water tap. Before each filtration the filtering surface of the candle may be renewed by rubbing with sand paper. The filtration apparatus is illustrated in Fig. 7.

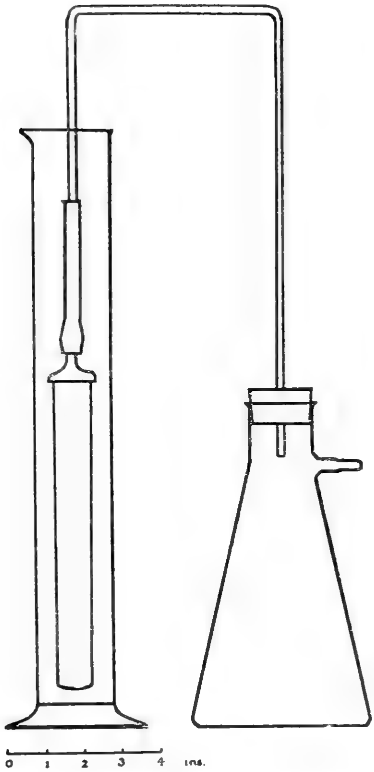

Fig. 7—Apparatus for the filtration of aqueous soil extracts for salt determinations.

(*b*) *Analysis of Extract.*—The Cl ion is determined by titration of an aliquot portion of the extract with standard silver nitrate solution of convenient strength, say, 1 ml. = .001 gm. Cl. Bicarbonate and carbonate ions are determined on 100 ml. by titration with N/10 sulphuric acid first with phenolphthalein as indicator followed by methyl orange.

The nitrate ion is determined either colorimetrically by the nitro phenol method or by a reduction method.

Nitrate is usually present in small quantities only, and is best determined separately by leaching a separate portion of the soil, as described on page 42.

Sulphate is determined by precipitation as barium sulphate.

Total Salts.—Evaporate 100 ml. of the water extract in a tared platinum dish over a water bath ; when the volume is reduced to about 5 ml. add 2 ml. of 20 vol. hydrogen peroxide, free from salts, to oxidize soluble organic matter and evaporate again to dryness. Dry in an oven at 110° C. for one hour and weigh.

Cations ; Ca, Mg, Na, K are determined by methods similar to those outlined under methods for replaceable bases.

Presence of Gypsum.—Where much gypsum is present it will not be possible to extract it completely under the above conditions. In such a case shake 10–20 grms. of soil with 200-500 ml. of 1 per cent. free hydrochloric acid (according to the amount of gypsum present). Shake for 8–16 hours and filter through a dry filter paper, rejecting the first runnings. Concentrate an aliquot portion and precipitate the sulphate in boiling solution by the addition of an excess of 10 per cent. barium chloride. Allow the precipitate to stand over night, filter, and wash. Ignite and weigh. Test for any silica by evaporation with hydrofluoric and sulphuric acids, and re-ignition.

6. Total Nitrogen.

Transfer 10 g. of soil to a flat-bottomed pyrex kjeldahl digestion flask and add 10 ml. of water. Shake. and allow to stand for half an hour.* Then add 30 ml. of concentrated sulphuric acid and start the digestion over a small flame, gradually increasing the heat until white fumes of sulphuric acid are produced. Remove the flask and add 10 g. of potassium sulphate and a crystal of copper sulphate. Replace the flask and continue the digestion until the black colour disappears. Then allow the flask to cool, dilute the contents with about 100 ml. of water, and transfer the fluid part to a 750–1,000 ml. conical flask, leaving as much as possible of the sand behind. Wash the sandy residue with four or five lots of 50–60 ml. of water, decanting the washings into the conical flask. Add a piece of granulated zinc to the contents of the latter, and then 100–110 ml. of concentrated caustic soda solution (1 lb. of caustic soda+1 litre of water), pouring the caustic solution down the side of the flask so that it forms a heavy layer at the bottom. Place the stopper in the flask and connect it to the distillation outfit. Mix the contents well by shaking and commence the distillation. Distil until about a quarter to a third of the liquid has passed over, the ammonia being collected in either—

(*a*) 25 ml. of N/10 hydrochloric or sulphuric acid, or
(*b*) a 4 per cent. solution of boric acid.†

(*a*) If tenth normal acid is used to absorb the ammonia, add two or three drops of methyl red indicator (1 g. of methyl red dissolved in 50 ml. of 95 per cent. alcohol, 50 ml. of water added. and the solution filtered if necessary), and when the distillation is completed titrate the excess of the standard acid with tenth normal sodium hydroxide.

The amount of nitrogen=ml. of N/10 sodium hydroxide used in a blank determination—ml. of N/10 sodium hydroxide used in the actual determination × .0014.

(*b*) *Winkler's Modification.*—Collect the distillate in an excess of a 4 per cent. solution of boric acid (50 ml. is a suitable quantity to use). The temperature of the distillate must never exceed 50° C. When the distillation is complete, add 10–15 drops of congo red indicator (0.25 g. of congo red dissolved in 100 ml. of 50 per cent. alcohol) and titrate the ammonia absorbed with N/10 sulphuric acid.

The amount of nitrogen=ml. of N/10 sulphuric acid used—ml. of N/10 sulphuric acid used in a blank determination ×.0014.

In using this modification, should the distillate be sucked back into the distilling flask it is only necessary to add more boric acid and continue the distillation.

7. Nitrogen as Nitrate and Ammonia.

Nitrates.—Where the soil does not contain appreciable quantities of organic matter the following procedure may be recommended :—

The soil sample as brought in from the field is broken up into pieces not more than half an inch in diameter and 150 grms. to 250 grms. weighed

* The Determination of Nitrogen in Heavy Clay Soils, D. V. Bal. *Journ. Agric. Sci.*, 15. pp. 454–459 (1925).

† Winkler's Modification. K. S. Markley and R. M. Hann. *Journ. Assoc. Off. Agric. Chem.*, 8, pp. 455–467 (1925).

out and dried in an oven at 55°–60° C. The drying is necessary to check nitrification, and also enables the subsequent washing to be carried out with a minimum puddling of the soil. Transfer the dry soil to a Buchner funnel using a hardened filter paper (Whatman No. 50), and pour on sufficient distilled water to cover the soil. After a few minutes' soaking connect to the filter pump and continue to leach the soil with successive quantities of distilled water until about 600 ml. of filtrate have been obtained; transfer the filtrate to a conical flask used in the nitrogen distillation apparatus, evaporate to 200 ml. with 1 grm. of magnesium oxide, and cool. Add 70 ml. of 30 per cent. caustic soda and reduce to ammonia with 2 grms. of Devarda alloy or with 5 grms. each of zinc dust and powdered iron. The reduction with Devarda alloy is complete in half an hour. With zinc and iron powders, allow the action to proceed gently in the cold for half an hour, continue for half an hour over a very small flame, and distil over the ammonia produced in a third period of half an hour.

Where much organic matter is present, E. J. Russell* recommends the following procedure :—

The water extract of the soil is poured into a flask covered by an inverted porcelain crucible lid, 10 ml. of 8 per cent. caustic soda and 10 ml. of 3 per cent. potassium permanganate are added and the whole is then boiled down to 75 ml. and kept just boiling for six hours. If the permanganate is completely decolourized, a little more is added until no appreciable change is noticeable in half an hour. The solution is diluted to 300 ml., 3 grms. of Devarda alloy added, 20 ml. of 40 per cent. caustic soda, and 5 ml. of alcohol. After reduction in the cold for a few minutes, the whole is distilled down to 50 ml., the ammonia produced being absorbed in N/50 sulphuric acid.

Ammonia.—As with nitrate, the quantity of ammonia fluctuates, and the soil sample must be examined straight from the field. In the method of D. V. Matthews†, which demands special apparatus, to 25 grms. of soil placed in the aerating tube of the apparatus are added 50 ml. of a solution containing 150 grms. of sodium chloride and 108 grms. of sodium carbonate per litre and 1 ml. of kerosene. A vigorous current of air, free from ammonia, is drawn through the mixture for five to six hours and the ammonia set free collected in N/50 sulphuric acid, using methyl red as indicator.

W. McLean and G. W. Robinson‡ have obtained results which closely agree with the above by leaching the soil with normal sodium chloride solution. The extract is distilled with magnesia. J. A. Prescott§ has used 5 per cent. potassium sulphate for extracting soil ammonia, and obtained 90 per cent. recovery as compared with the aeration method.

8. Organic Carbon and Humus.

Organic carbon is preferably to be determined by direct dry combustion. Although methods of wet combustion have been recommended at various times, the oxidation of carbon so obtained is usually incomplete, and there is a general tendency amongst workers to revert back in all cases to the combustion furnace.

* Russell, E. J. "Soil Conditions and Plant Growth," p. 453 (1927).
† Matthews, D. V. *Journ. Agric. Sci.*, 10, p. 72 (1920).
‡ McLean, W., and Robinson, G. W. *Journ. Agric. Sci.*, 14, p. 548 (1924).
§ Prescott, J. A. *Sultanic Agric. Soc. Bull.* No. 2 (1920).

Where soils contain calcium carbonate, this may be removed before combustion by evaporating the soil with weak inorganic acids, such as sulphurous or phosphoric acid.

*Humus.**—Methods for the determination of soil humus are based on the definition of humus as being that portion of the soil organic matter which is soluble in alkali after the soil has been previously treated with dilute acid to remove calcium carbonate and to decompose insoluble humates.

Degree of Humification of Soil Organic Matter.—In the method proposed by Robinson and Jones, the humified portion of the soil organic matter is presumed to be completely decomposed or made entirely soluble by oxidation with hydrogen peroxide. A portion of the soil is heated in a beaker at 100° C. for fifteen minutes with 60 ml. of 6 per cent. hydrogen peroxide. The contents of the beaker are finally boiled and then filtered and washed repeatedly with hot water. The residue is washed into a flat porcelain dish, and the amount of unaltered organic matter determined by ignition after drying to constant weight at 100° C. The difference between the loss on ignition before and after treatment with hydrogen peroxide, is presumed to represent that portion of the soil organic matter which is humified. It is probable that this method has a limited application particularly in the case of soils rich in clay or calcium carbonate. In addition to the loss on ignition, the determination of organic carbon has been suggested as affording a more useful index in this connexion.

Humus soluble in sodium hydroxide.—In the method of Eden, 5 grms. of soil in a gooch crucible are treated with 50 ml. of 10 per cent. hydrochloric acid and then well washed. The soil is then transferred through a wide-necked funnel to a 100 ml. conical flask previously calibrated with a mark giving the volume of the soil plus 100 ml. About 60 ml. of water are used for this operation, 20 ml. of 50 per cent. caustic soda are then added by inserting the end of the pipette a little way below the water. The flask is then filled to the mark with water, a few drops of alcohol being used to clear the meniscus if necessary. The flask is then immersed up to the neck in a water bath at 100° C. for fifteen minutes, during which time the contents are constantly stirred, a portion of the hot solution is then filtered through a hardened filter paper (No. 50 Whatman) on a Buchner funnel. It is unnecessary and inadvisable to collect more than 20 ml. of the extract. Ten ml. of the cooled extract are then diluted to 200 ml., and the colour compared in a colorimeter with that of a standard prepared from *acidum huminicum* (Merck).

The method of Joseph and Whitfeild, which is specially suited for heavy alkaline soils, is as follows :—

One gram of the soil is treated in a centrifuge tube with dilute hydrochloric acid to decompose calcium and magnesium carbonates and humates and is then washed in the centrifuge until free from acid. A measured quantity 50 ml. of 4 per cent. sodium hydroxide is then added, and the soil shaken up and allowed to stand for 24 hours. The tube is centrifuged until the liquid is clear, and its colour then compared in the colorimeter with a standard solution of humus prepared from a similar soil.

* No method for the determination of humus has as yet been finally adopted at the Waite Institute. Of the methods available, the following, which are described above, have been selected for further investigation :—Eden, T., *Journ. Agric. Sci.*, 14, pp. 468–472 (1924) ; Joseph, A. F., and Whitfeild, B. W., *Journ. Agric. Sci.*, 17, pp. 1–11 (1927) ; Robinson, G. W., and Jones, J. O., *Journ. Agric. Sci.*, 15, pp. 26–29 (1925).

Details of this humus preparation are to be found in the original paper.

According to C. W. B. Arnold,* the soluble humus consists of two parts, that soluble in cold dilute alkali, and a further portion which will not dissolve until the dilute alkali is heated. There is a further possibility that the extraction as carried out by the above methods represents an equilibrium between the solution and the soil and not a complete extraction.

9. Soil Reaction.

The indicator methods, although of use for general work, cannot usually be recommended with soils unless the electrometric method is not available. The quinhydrone method described below is very convenient, and in practice more rapid than the colorimetric methods. For orientation and field work a number of simple tests are available. The

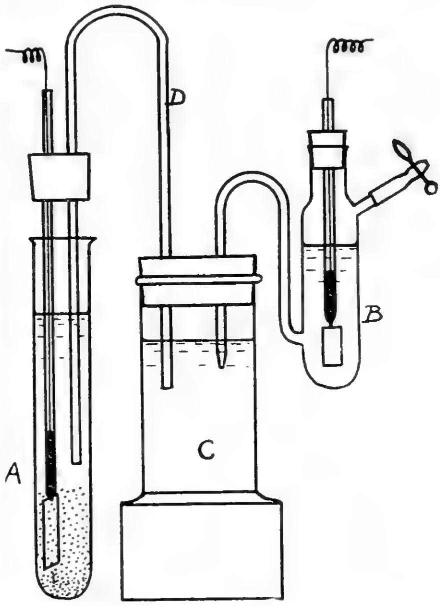

Fig. 8—Apparatus for the determination of the hydrogen-ion concentration of the soil by the quinhydrone electrode after Biilmann and Torborg-Jensen.

Comber test, which has found wide application in Europe, has been tested with success in South Australian soils, and has been found to divide, quite sharply, acid from neutral or alkaline soils.† For air-dried soils, the original Comber reagent, saturated alcoholic potassium thiocyanate,‡ can be recommended. The modified test,§ using aqueous 5 per cent. potassium salicylate, can be employed directly with moist soils. In practice 5 grms. of the soil are treated with 10 ml. of the reagent, a pink or red colour developing with potassium thiocyanate and a reddish-brown colour with the salicylate. The intensity of the colour is roughly proportional to the degree of acidity. Professor Comber has privately expressed his preference to the authors for the original thiocyanate method wherever practicable.

* Arnold, C. W. B. *Journ. Agric. Sci.*, in the press.
† J. A. Prescott, *Proc. Roy. Soc. South Aust.*, 51, pp. 287–290 (1927).
‡ N. B. Comber, *Journ. Agric. Sci.*, 10, p. 420 (1920).
§ N. B. Comber, *Journ. Agric. Sci.* 12, p. 370 (1922)

The "Soil Testing Outfit" placed on the market by the British Drug Houses Ltd., makes use of a mixed indicator, and gives quite useful approximate indications of the pH values at intervals of 0.5 units.

(a) Electrometric Determination of Soil Reaction.*

The most convenient method for the determination of the hydrogen-ion concentration of the soil is based on the quinhydrone electrode method of Biilmann.†

Where cross reference is required to the hydrogen electrode, the technique recommended by Crowther‡ should be followed.

The apparatus most recently recommended is illustrated in Fig. 8.

The electrode vessel B forms the standard electrode. It contains 15 ml. of the standard electrolyte of the strength KCl 0.09N and HCl 0.01N, previously shaken with 0.1 gm. quinhydrone.

The central vessel C contains 3.5 molar potassium chloride.

A consists of a test tube 1.5 cm. × 15 cm. which forms the soil electrode vessel. The connexion between the soil suspension in A and the solution in C is made through a syphon tube D filled with a 3.5N solution of potassium chloride in a stiff 5 per cent. agar jelly.

The electrodes in A and B are of bright platinum.

Method.—Place 10 gms. of soil and 10 ml. of aerated distilled water in a test tube, add 0.1 gm. of quinhydrone, shake for two or three seconds, and place in the position A in the apparatus as shown.

The potentials are read with an accuracy corresponding to 0.01–0.02 in pH values.

By weighing out a number of soil samples into a range of standard test tubes it is readily possible to make a relatively large number of successive determinations, as equilibrium is attained very rapidly.

A control determination is made at the beginning and end of each day's work, using a buffer solution. M/20 potassium hydrogen phthalate, which has a pH value of 3.97 at 20° C., is very convenient to prepare and to use.

After the use of a buffer solution, the electrode should be well washed, but this washing need not be so thorough when dealing with successive soil samples.

It is preferable to set up a fresh standard electrode daily.

The reaction of the soil is calculated from the following equation, where π is the measured difference in potential between the two electrodes :—

$$pH = \frac{0.118 - \pi}{0.0001984T}$$

The pH values can be read directly from Table 3 for temperatures between 10° C. and 25° C.

Preparation of Quinhydrone.—Dissolve 100 grms. of ferric ammonium alum in 300 ml. of distilled water. Heat to 65° C., pour with stirring into a solution of 25 grms. hydroquinone in 100 ml. distilled water, previously heated to the same temperature. Cool the mixture, filter off the fine needles of quinhydrone on a Buchner funnel, wash with ice-cold water. Dry between sheets of filter paper at room temperature.

* E. Biilmann and S. Torborg-Jensen: Transactions of the 2nd Commission of the Int. Soc. of Soil Science, Vol. B, pp. 236–274 (1927).

† E., Biilmann, *Journ. Agric. Sci.* 14, p. 232 (1924).

‡ E. M. Crowther, *Journ. Agric. Sci.*, 15, p. 201 (1925).

TABLE 3.—CONVERSION OF π TO pH AT DIFFERENT TEMPERATURES. (QUINHYDRONE ELECTRODE.)

$$pH = \frac{0.118 - \pi}{0.0001984\ T.}$$

π*	10°	11°	12°	13°	14°	15°	16°	17°
	pH	pH	pH	pH	pH	pH	pH	pH
.100	3.88	3.87	3.85	3.84	3.83	3.81	3.80	3.79
.110	4.06	4.05	4.03	4.02	4.00	3.99	3.98	3.96
.120	4.24	4.22	4.21	4.19	4.18	4.16	4.15	4.14
.130	4.42	4.40	4.39	4.37	4.35	4.34	4.32	4.31
.140	4.59	4.58	4.56	4.55	4.53	4.51	4.50	4.48
.150	4.77	4.76	4.74	4.72	4.71	4.69	4.67	4.66
.160	4.95	4.93	4.92	4.90	4.88	4.86	4.85	4.83
.170	5.13	5.11	5.09	5.07	5.06	5.04	5.02	5.01
.180	5.31	5.29	5.27	5.25	5.23	5.21	5.20	5.18
.190	5.48	5.47	5.45	5.43	5.41	5.39	5.37	5.35
.200	5.66	5.64	5.62	5.60	5.58	5.56	5.55	5.53
.210	5.84	5.82	5.80	5.78	5.76	5.74	5.72	5.70
.220	6.02	6.00	5.98	5.96	5.94	5.91	5.89	5.88
.230	6.20	6.17	6.15	6.13	6.11	6.09	6.07	6.05
.240	6.37	6.35	6.33	6.31	6.29	6.26	6.24	6.22
.250	6.55	6.53	6.51	6.48	6.46	6.44	6.42	6.40
.260	6.73	6.71	6.68	6.66	6.64	6.61	6.59	6.57
.270	6.91	6.89	6.86	6.84	6.81	6.79	6.77	6.74
.280	7.09	7.06	7.04	7.01	6.99	6.96	6.94	6.92
.290	7.27	7.24	7.22	7.19	7.17	7.14	7.12	7.09
.300	7.44	7.42	7.39	7.37	7.34	7.31	7.29	7.27
.310	7.62	7.59	7.57	7.54	7.52	7.49	7.46	7.44
.320	7.80	7.77	7.75	7.72	7.69	7.66	7.64	7.61
.330	7.98	7.95	7.92	7.89	7.87	7.84	7.81	7.79
.340	8.16	8.13	8.10	8.07	8.04	8.01	7.99	7.96
.350	8.33	8.30	8.28	8.25	8.22	8.19	8.16	8.14
.360	8.51	8.48	8.45	8.42	8.39	8.36	8.34	8.31
.370	8.69	8.66	8.63	8.60	8.57	8.54	8.51	8.48
.380	8.87	8.84	8.81	8.78	8.75	8.72	8.69	8.66
.390	9.05	9.01	8.98	8.95	8.92	8.89	8.86	8.83
.400	9.22	9.19	9.16	9.13	9.10	9.06	9.03	9.00
.410	9.40	9.37	9.34	9.31	9.27	9.24	9.21	9.18
.420	9.58	9.55	9.51	9.48	9.45	9.41	9.38	9.35
.430	9.76	9.72	9.69	9.66	9.62	9.59	9.56	9.53
.440	9.94	9.90	9.87	9.83	9.80	9.76	9.73	9.70
.450	10.11	10.08	10.04	10.01	9.98	9.94	9.91	9.87

* All these voltages are negative.

PROPORTIONAL PARTS.

π	Diff. = .17	Diff. = .18	π	Diff. = .17	Diff. = .18	π	Diff. = .17	Diff. = .18
	pH	pH		pH	pH		pH	pH
.0005	0.01	0.01	.0040	0.07	0.07	.0075	0.13	0.13
.0010	0.02	0.02	.0045	0.08	0.08	.0080	0.14	0.14
.0015	0.03	0.03	.0050	0.09	0.09	.0085	0.14	0.15
.0020	0.03	0.04	.0055	0.09	0.10	.0090	0.15	0.16
.0025	0.04	0.04	.0060	0.10	0.11	.0095	0.16	0.17
.0030	0.05	0.05	.0065	0.11	0.12	.0100	0.17	0.18
.0035	0.06	0.06	.0070	0.12	0.13			

TABLE 3.—CONVERSION OF π TO pH AT DIFFERENT TEMPERATURES.
(QUINHYDRONE ELECTRODE.)

$$pH = \frac{0.118 - \pi}{0.0001984\ T.}$$

π*	18°	19°	20°	21°	22°	23°	24°	25°
	pH	pH	pH	pH	pH	pH	pH	pH
.100	3.78	3.76	3.75	3.74	3.72	3.71	3.70	3.69
.110	3.95	3.94	3.92	3.91	3.89	3.88	3.87	3.86
.120	4.12	4.11	4.09	4.08	4.07	4.05	4.04	4.03
.130	4.30	4.28	4.27	4.25	4.24	4.22	4.21	4.19
.140	4.47	4.45	4.44	4.42	4.41	4.39	4.38	4.36
.150	4.64	4.63	4.61	4.59	4.58	4.56	4.55	4.53
.160	4.82	4.80	4.78	4.77	4.75	4.73	4.72	4.70
.170	4.99	4.97	4.95	4.94	4.92	4.90	4.89	4.87
.180	5.16	5.14	5.13	5.11	5.09	5.07	5.06	5.04
.190	5.33	5.32	5.30	5.28	5.26	5.24	5.23	5.21
.200	5.51	5.49	5.47	5.45	5.43	5.41	5.40	5.38
.210	5.68	5.66	5.64	5.62	5.60	5.58	5.57	5.55
.220	5.85	5.83	5.81	5.79	5.77	5.75	5.74	5.72
.230	6.03	6.01	5.99	5.97	5.95	5.92	5.91	5.89
.240	6.20	6.18	6.16	6.14	6.12	6.09	6.08	6.05
.250	6.37	6.35	6.33	6.31	6.29	6.27	6.25	6.22
.260	6.55	6.53	6.50	6.48	6.46	6.44	6.41	6.39
.270	6.72	6.70	6.67	6.65	6.63	6.61	6.58	6.56
.280	6.89	6.87	6.85	6.82	6.80	6.78	6.75	6.73
.290	7.07	7.04	7.02	6.99	6.97	6.95	6.92	6.90
.300	7.24	7.22	7.19	7.17	7.14	7.12	7.09	7.07
.310	7.41	7.39	7.36	7.34	7.31	7.29	7.26	7.24
.320	7.59	7.56	7.53	7.51	7.48	7.46	7.43	7.41
.330	7.76	7.73	7.71	7.68	7.65	7.63	7.60	7.58
.340	7.93	7.91	7.88	7.85	7.82	7.80	7.77	7.75
.350	8.11	8.08	8.05	8.02	8.00	7.97	7.94	7.92
.360	8.28	8.25	8.22	8.20	8.17	8.14	8.11	8.08
.370	8.45	8.42	8.39	8.37	8.34	8.31	8.28	8.25
.380	8.63	8.60	8.57	8.54	8.51	8.48	8.45	8.42
.390	8.80	8.77	8.74	8.71	8.68	8.65	8.62	8.59
.400	8.97	8.94	8.91	8.88	8.85	8.82	8.79	8.76
.419	9.15	9.11	9.08	9.05	9.02	8.99	8.96	8.93
.420	9.32	9.29	9.26	9.22	9.19	9.16	9.13	9.10
.430	9.49	9.46	9.43	9.40	9.36	9.33	9.30	9.27
.440	9.66	9.63	9.60	9.57	9.53	9.50	9.47	9.44
.450	9.84	9.80	9.77	9.74	9.70	9.67	9.64	9.61

* All these voltages are negative.

PROPORTIONAL PARTS.

π	Diff. = .17	Diff. = .18	π	Diff. = .17	Diff. = .18	π	Diff. = .17	Diff. = .18
	pH	pH		pH	pH		pH	pH
.0005	0.01	0.01	.0040	0.07	0.07	.0075	0.13	0.13
.0010	0.02	0.02	.0045	0.08	0.08	.0080	0.14	0.14
.0015	0.03	0.03	.0050	0.09	0.09	.0085	0.14	0.15
.0020	0.03	0.04	.0055	0.09	0.10	.0090	0.15	0.16
.0025	0.04	0.04	.0060	0.10	0.11	.0095	0.16	0.17
.0030	0.05	0.05	.0065	0.11	0.12	.0100	0.17	0.18
.0035	0.06	0.06	.0070	0.12	0.13			

(b) Colorimetric Method.*

Twenty grms. of soil are treated with 60 ml. of distilled water and shaken for one hour. The soil extract is now centrifuged for ten to twenty minutes and 10 ml. withdrawn by means of a pipette and transferred to a test tube. Twenty drops of indicator are now added, and the colour compared with that of the standard pair of tubes used in the drop ratio method. Where the soil extract is coloured in itself it is necessary to place a tube containing the extract without indicator behind the pair of indicator tubes. In many cases, particularly with alkaline soils, it is almost impossible to obtain clear extracts except by filtration through porcelain filters. Micro filters of this type, similar to those used in the filtration for soluble salts, have been used, but the filtration is very tedious.

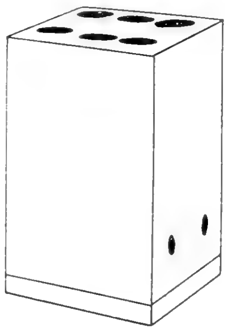

Fig. 9—Comparator for use in the colorimetric method for the determination of the hydrogen-ion concentration of soil extracts after Gillespie.

Gillespie has used colloidal iron to clear soil extracts, but was not able to recommend this procedure except where experience had shown the method to be reliable for the soils under investigation.

The colour standards are prepared without the use of buffer solutions by the drop ratio method of Gillespie. Ten drops of indicator are shared by two tubes, one of which is entirely acid, and the second entirely alkaline. By looking through both tubes in a comparator illustrated in Fig. 9, the colour observed is the result of a definite ratio between the two forms of the indicator and the pH values may be calculated from the following equation :—

$$pH = K + \log \frac{\text{Alkaline form}}{\text{Acid form}}$$

where K is the apparent dissociation constant of the indicator expressed in terms of the hydrogen-ion exponent.

A range of test tubes, each containing 5 ml. of distilled water made acid and alkaline in pairs, and to which ten drops in all of indicator have been added to each pair of tubes, can be readily set up.

The table of pH values for various drop ratios of each indicator as given by Gillespie is set out in Table 4.

* Gillespie, L. J. *Journ. Wash. Acad. Sci.*, 6, p. 12 (1916).
Gillespie, L. J. *Soil Science*, 9, pp. 115–136 (1920).

TABLE 4.

L. J. GILLESPIE'S DATA FOR THE DETERMINATION OF THE HYDROGEN-ION EXPONENT BY MEANS OF THE DROP RATIO INDICATOR METHOD.

Drop—ratio.	Hydrogen-Ion Exponent for each Pair of Tubes.						
	Brom-phenol blue.	Methyl red.	Brom-cresol purple.	Brom-thymol blue.	Phenol red.	Cresol red.	Thymol blue.
1 : 9	3.1	4.05	5.3	6.15	6.75	7.15	7.85
(1.5 : 8.5)	3.3	4.25	5.5	6.35	6.95	7.35	8.05
2 : 8	3.5	4.4	5.7	6.5	7.1	7.5	8.2
3 : 7	3.7	4.6	5.9	6.7	7.3	7.7	8.4
4 : 6	3.9	4.8	6.1	6.9	7.5	7.9	8.6
5 : 5	4.1	5.0	6.3	7.1	7.7	8.1	8.8
6 : 4	4.3	5.2	6.5	7.3	7.9	8.3	9.0
7 : 3	4.5	5.4	6.7	7.5	8.1	8.5	9.2
8 : 2	4.7	5.6	6.9	7.7	8.3	8.7	9.4
(8.5 : 1.5)	4.8	5.75	7.0	7.85	8.45	8.85	9.55
9 : 1	5.0	5.95	7.2	8.05	8.65	9.05	9.75
Per cent. in indicator solution ..	0.008	0.008	0.012	0.008	0.004	0.008	0.008
Cubic centimetres of 0.1 N NaOH per 0.1 gm. portion ..	1.64	..	2.78	1.77	3.10	2.88	2.38
Produce acid colour with	0.05N HCl	0.05N HCl	0.05N HCl	0.05N HCl	0.05N HCl	2% H_2KPO_4	2% H_2KPO_4 or H_2O
Quantity of acid used to produce acid colour	1 ml.	1 drop	1 drop	1 drop	1 drop	1 drop	1 drop

10. Lime Requirement.

Although various methods are available for the determination of the lime requirement of the soil, no uniformity has been reached as to their application.*

European and American practice is in favour of the determination of some measure of titratable acidity by methods dependent upon the liberation of acid from sodium or calcium acetates or neutral salts such as potassium chloride.

The methods in use at the present time may be grouped under four headings :—

(1) The decomposition by the soil of salts of weak acids—calcium carbonate as in the method of Tacke,† zinc sulphide as in the method of Truog,‡ and sodium, calcium or potassium acetates as used by Jones§

* In the laboratories of the Queensland Department of Agriculture the methods of Hutchinson-MacLennan, Jones and Hopkins have all been employed.

† Tacke, B. *Chem. Zeit.* 21, p. 174 (1897). Wiley. Principles and Practice of Agric. Analysis, Vol. I. 400, (1926).

‡ Truog, E. Wisc. Agr. Expt. Stat. Bull. 312. (See also F. W. Parker and T. W Tidmore. *Soil Sci.* 16, p. 75, 1923.)

§ Jones, C. H. *Journ. A.O.A.C.* 1, pp. 43–44 (1915). Wiley, p. 411, 1926. (See also E. A Carleton, *Soil Science*, 16, pp. 79–90, 1923.)

in America and Kappen* in Europe. In the first two methods the product of reaction is a gas which can be collected, and it may be expected that an end point will be reached as the gas can be removed from the reaction. In the case of the acetate method, the final result expresses a condition of equilibrium between the soil and the reacting solution.

(2) The neutralization of the soil with barium or calcium hydroxide. In these methods successive quantities of soil are treated with varying amounts of the alkali, and the end point determined by selecting that particular concentration of alkali which gives the desired soil reaction—neutrality to litmus in the original Veitch† method (1904). In the recent method of D. J. Hissink‡ the end point is determined by conductimetric titration.

(3) The equilibrium between the soil and a standard solution of calcium bicarbonate as in the method of Hutchinson and MacLennan.

(4) The equilibrium between the soil and solutions of neutral salts as in the methods of Hopkins§ (1902) and Daikuhara|| (1914).

With the advent of the newer conceptions of soil saturation, attempts have been made to determine the total titratable acidity of the soil by an estimate of the degree of soil unsaturation; of these methods possibly that recently suggested by O. Gehring, A. Peggau, and O. Wehrmann¶ offers the most logical presentation of an attempt to solve the problem.

The exchangeable bases in a sample of the soil are first to be determined by one of the standard methods. Another sample of soil is then to be saturated with calcium and the replaceable bases are to be determined. In this method the soil to be investigated is first treated with an excess of calcium hydroxide solution and shaken for 30 minutes to establish equilibrium. Carbon dioxide is then passed to convert the hydroxide to carbonate, using phenolphthalein as an indicator. The excess of carbon dioxide is then removed by blowing air through the heated solution. In this way a saturated soil is obtained with a slight excess of calcium carbonate, and the replaceable bases can be readily determined.

Hutchinson and MacLennan's method, which is given below, can be recommended as a basis for further local investigation. For a discussion of this method, see E. M. Crowther and W. S. Martin.**

Hutchinson and MacLennan's Method.—The calcium bicarbonate is most rapidly prepared by means of a "Sparklet" syphon using excess of calcium carbonate in suspension. The contents of the syphon should be diluted with one-third its volume of distilled water to give approximately N/50 concentration of calcium bicarbonate.

For a determination of acidity, or lime requ rement, 10–20 grms. of the soil are placed in a bottle of 500–1,000 ml. capacity together with 200–300 ml. of the approximately N/50 solution of calcium bicarbonate,

* Kappen, H. Trans. 2nd Comm. Int. Soc. Soil Sci. B., p. 179 (1927).
† Veitch, F. B. *J. Amer. Chem. Soc.* 26, p. 637 (1904). *Journ. A.O.A.C.* 3, p. 372 (1920). Wiley, p. 409 (1926).
‡ Hissink, D. J. Trans. 2nd Comm. Int. Soc. Soil Sci. B. p. 186 (1927).
§ Hopkins, C. G. U.S.D.A. Bur. Chem. Bull. 107, p. 20 (1912).
|| Daikuhara. Bull. Imp. Cent. Agric. Expt. Sta., Japan, 2, p. 32 (1914).
¶ *Zeits. f. Pfl. v. Dung. A.* 8, p. 321 (1927).
** Crowther, E. M. and Martin, S. W. *Journ. Agric. Sci.* 15, p. 237, (1925).

and the air in the bottle is displaced by a current of carbon dioxide in order to ensure against possible precipitation of the calcium carbonate during the period of determination. The bottle is then placed in a shaking machine for three hours, after which time it is opened, the liquid is filtered, and a portion of the filtrate equal to half of the original amount of bicarbonate solution is titrated against N/10 acid, using methyl orange as indicator. The difference between this final titration and that of the initial solution represents the amount of calcium carbonate absorbed, each milli-litre of N/10 acid being equal to 5 mgrms. calcium carbonate.

V.—LABORATORY EXAMINATIONS REQUIRED FOR SOIL SURVEYS.

The purpose of the laboratory examination in soil survey work is as an aid to the more precise classification of the soils to be examined. The British school relies on the geological drift maps for the field description of the soil followed by mechanical analysis to define the physical texture of the soil, which has an important bearing on the suitability of the soil for the cultivation of specific crops. British soils fall, however, into three main international groups—

Brown woodland soils, weakly leached (podsolized),
Woodland soils, moderately leached (podsolized),
High moor or mountain soils—

and the bulk of the survey work has been confined to the agricultural zones of the first two classes.

The international groups of soils cover a much wider range of climatic conditions, so that chemical work is of importance in defining the group to which any given soil belongs. H. L. Shantz and C. F. Marbut* have criticized the British chemical data which relies on the hydrochloric acid extract of the soil as of little value for the purpose of soil classification, and the United States Soil Survey organization relies on complete analyses. As the chemical characteristics of the international system are generally related to the climatic conditions, other criteria are available, the chief among which may be cited : soil reaction, degree of saturation of the soil with calcium or hydrogen ions for the characterization of acid soils and the degree of saturation with sodium for the study of "alkali" soils, and the ultimate chemical composition of the clay fraction with special reference to the silica : alumina ratio and the water of constitution. This is specially important with regard to laterite soils,† and may have an important bearing on some of the physical properties of the soil such as plasticity.

In view of the above the essential determinations for the characterization of a soil may be suggested as—

1. Mechanical analysis.
2. Organic matter—including organic carbon, humus, and nitrogen.
3. Calcium carbonate.
4. Soil reaction expressed as pH value.

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* Soils and Vegetation of Africa. American Geographical Society. Research Series No. 13, pp 134–136 (1923).

† Martin, F. J. *Tropical Agriculture* 4, p. 165 (1927).

5. Analysis of the clay fraction with special reference to combined water and silica, alumina and iron.
6. Exchangeable bases.
7. In the case of arid soils—soluble salts.

In the course of soil survey work the necessary laboratory examinations may be classified as follows :—

On all samples—

(1) Mechanical analysis with the implied loss on ignition and calcium carbonate.
(2) Nitrogen.
(3) Reaction.
(4) Water soluble salts where present in sufficient amount.

On the major type samples—

(5) Replaceable bases.
(6) Analysis of the clay fraction.
(7) Lime requirement and titration curves (buffer action).
(8) Complete analysis of soluble salts.
(9) Humus (degree of humification of organic matter) and organic carbon.
(10) Acid extractions for plant nutrients.

In some soil types a mineralogical examination of the fine sand fraction may give useful information together with possibly a complete analysis of the fractions separated by mechanical analysis.

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COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

A Forest Products Laboratory for Australia

Justification for its Creation
Outline of its Organization
and Rough Estimate of Cost

By

A. J. GIBSON, F.C.H., F.L.S., F.Z.S.
Indian Forest Service

MELBOURNE, 1928

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C.8262.

PREFACE.

Since its inception, the Council has received a large number of requests to carry out investigations on problems relating to forest products. It has also been urged to establish a forest products laboratory in order to give appropriate effect to such requests.

The matter was regarded as of such importance that, some time ago, steps were taken to obtain advice on the whole question from a highly qualified authority. At the request of the Commonwealth, the Government of India agreed to make available the services of Mr. A. J. Gibson, F.C.H., F.L.S., F.Z.S., Conservator of Forests, Bihar and Orissa, for the purpose.

Mr. Gibson reached Australia in August, 1927, and after spending nearly four months visiting all States of the Commonwealth, thus becoming conversant with Australian conditions, he duly furnished a report.

This report is printed on the pages that follow. In making it available, the Council desires to indicate that such action does not mean that the opinions expressed therein are its adopted views, nor that it is intended to follow, in their entirety, the recommendations made.

C.8262.—2

CONTENTS.

A Forest Products Laboratory for Australia.

Justification for its Creation, Outline of its Organization, and Rough Estimate of its Cost.

I. INTRODUCTION.

The need for an inquiry into the subject of a Forest Products Laboratory for Australia was foreshadowed in paragraph 13, pages 22–24, of the *Journal of the Council for Scientific and Industrial Research* for August, 1927 (Vol. 1, No. 1), and as stated therein, steps were taken to secure my services on loan from the Government of India for a period of five months to investigate on the spot forest conditions in Australia and the necessity or otherwise of taking up intensive scientific research into Australian forest products and their uses. I relinquished my duties under the Government of India on the afternoon of the 12th July, and after a few days of preparation started for Australia on the 17th July, reaching Fremantle on the 1st August and Sydney on the 12th August, 1927. Appendix I. gives details of my tour. Having completed my investigations, I left Fremantle on the 14th November and reached Ranchi on the 28th November, and having completed my report, resumed my duties under the Government of India on the afternoon of Saturday, the 10th December, 1927.

My acknowledgments are due for the courtesy and unstinted assistance given to me throughout my stay in Australia by Dr. Rivett and all the officers and members of the Executive and State Committees of the Council for Scientific and Industrial Research, by Mr. C. E. Lane-Poole, Inspector-General of Forests to the Commonwealth Government of Australia, and by forest officers and research workers on forest products in every State in Australia. Without this help the task set me would have been quite incapable of accomplishment in the time at my disposal, and even as it is I feel that I was only able to study cursorily the principal problems in forestry and forest utilization involved, by getting an idea of forest types, inspecting typical industries, utilizing forest products (see Appendix II.), acquiring as much knowledge of the bibliography concerned and getting to know as many of the research workers in forestry and forest products throughout Australia as possible.

To the last band of workers, Australia owes a debt of gratitude. Working generally alone, often unassisted and unguided, in cramped surroundings, with insufficient equipment, they have produced a volume of work which will considerably lighten the task of future workers in the realm of forest products and their scientific investigation. But while I gladly acknowledge the value of such work, I have to notice a great defect, as it neutralizes to a large extent the value of the research done. I refer to the absence of co-ordination among the States and also the Federal

Government in recording results and indexing literature, the outcome being that work has overlapped and research has been carried out under conditions which have lessened its value owing to the impossibility of comparing the data by reason of lack of standardization in the field and in the laboratory. This matter will be alluded to again later, and the present reference is only made because of the tremendous bearing this factor has on the necessity for co-ordination and classification of future research work in forestry and forest products in Australia. Money, time, and energy have been wasted in the past, and steps must be taken to see that this does not re-occur.

The past history of Australian efforts to study forest products and attempts to create a Forest Products Laboratory in the West is recorded in the Forest Reports of Western Australia. The latter resulted in Mr. I. H. Boas, M.Sc., of Adelaide, making a world-wide tour of forest research institutions in 1918 to 1920 and his writing an able report.

II. FORESTRY AND FOREST PRODUCTS: THEIR RELATION.

It is unnecessary for the purposes of this Report to go deeply into the history of forestry in Australia, though some reference is required, as obviously there can be no forest products research without forests. Details are available in the forest annual reports of the various States and in the articles on forestry in the official annual year books of the Commonwealth Government of Australia. Mr. G. C. Robertson's able report on Australian forestry published in 1926, by authority of the Government of the Union of South Africa, and entitled, "A Reconnaissance of the Forest Trees of Australia," is an up-to-date account worthy of close study.

It will consequently suffice to say here that at an interstate conference of forestry officers a few years ago the opinion was expressed that Australia could not do with less than 24,500,000 acres of forest permanently dedicated to meet the timber and other forest requirements of the Greater Australia which will some day come into being. This recommendation, as regards area, was endorsed at a subsequent meeting of State Premiers. The acreage is based on the forestry requirements of a population of 28,000,000 people. It is the forester's duty to look far ahead, for the trees do not grow in a day, and it is the duty of any responsible Government to see that the forester's considered recommendations are heeded and given effect to. So far the progress in the reservation of this acreage of forest has not been rapid or very satisfactory.

The rival claims of the Land Departments for acquiring land for settlement and of the Forest Departments for acquiring land for permanent reservation as State forests have not been adequately appraised at their respective values. The two Departments must work hand in hand, for Australia's future intensive agricultural and pastoral industries are indissolubly connected with intensive forestry, and the development of these vital primary industries, to say nothing of the ever-expanding secondary industries, depends largely on a far-sighted policy being adopted *now* in regard to the country's forest reservations.

The question now arises: Why is it necessary to make scientific investigation into forest products at all? At first sight the necessity is not quite clear to the lay mind, but a perusal of the following extract from the Decennial Record of the Forest Products Laboratory, Madison, Wisconsin, United States of America, for the period 1910–20 (published in 1921) will show, it is hoped, the relationship between wood and human progress in such a concise fashion that no further apologies will be required for the rather lengthy quotation:—

Knowledge is the torch of human progress. It throws its light forward and lifts each generation upward in the scale of civilization in proportion as that generation accepts its standards. In the story of creation, knowledge is symbolized by a tree. Down through the intervening ages man's use of wood in attaining new heights of knowledge has been one of the most important factors in the advance of civilization.

Primitive man, we are told, was dominated by the forest. But as his crude imagination slowly awakened to the arts of life, he finally succeeded in reversing the order of his environment by making the forests more and more serve his material needs. And in conquering the forests, he built up the material structure of his own civilization; he stimulated his latent consciousness of the power of civilization; he lifted himself from a life of savage and nomadic wandering to the social and industrial modernism of to-day.

History is rich in evidence of the achievement of human progress through knowledge derived from wood. Man, it is held, was rescued from a state of savagery primarily by two discoveries—the art of kindling fire at his will and the use of the bow and arrow, which made him master of his food supply and provided him with clothing. Ages later, the discovery of iron, with which he could fashion wood more and more to serve his needs, appears to have been the step from barbarism to the first stages of civilization.

It would be difficult to express proper appreciation of wood as a material stimulus to learning and the arts of living. Its ready adaptability, we can well believe, made it the sculptor's clay by which man tested and developed his first imaginative theories and laid the primitive foundation of much present-day science. The origin of the principle of the wheel, which is an essential part of almost every machine or mechanical conveyance of our own age, is lost in antiquity, as evidenced by wooden wheels taken from the monuments of ancient Egypt. In these same mounds are found the earliest recorded form of ploughs made from wood, with iron-tipped wedges. With these ploughs man acquired his first crude knowledge of extensive agriculture, and he used them, with slight modifications, until the first half of the eighteenth century.

With wood, man learned to build homes and create architecture; to construct ships and master navigation; to build bridges and develop the science of mechanics; to generate steam and harness its power for transportation. Modern electric and magnetic science owes its birth to fossil resin from coniferous forests which were prehistoric when Pliny, 70 years before the dawn of Christianity, recorded the fact that amber, when rubbed, acquired the power of attracting straws. Thus, in diverse ways, fundamental principles have first been worked out from wood, and the knowledge thus gained—primitive though it may now appear—has been applied in developing the use of stone, iron, steel, concrete, and other materials. The process still goes on. Within a decade, man has conquered the air with a wooden plane and is to-day applying the results of his experiments to the fabrication of an all-metal machine.

It is a striking fact that through the agency of wood, man has acquired more fundamental knowledge of related subjects than he has of the properties of wood itself. In the development of his wood craft, he has been likened to the growing child who, building with blocks, acquires an ever larger consciousness of their adaptability to new figures as experience matures his mind. Spurred by personal needs and the rewards of commercialism, however, man fashioned wood into many scores of standard products, about which trade-crafts took shape and became clearly defined through many centuries of competition and zealous individualism. He thus built up a great diversified mass of wood-using lore, based, not upon a scientific knowledge of the many different kinds of wood used, but upon rule of thumb methods, beliefs, customs, and prejudices, passed down from one generation to another as expanded by the increasing complexities of each changing age.

Into this accumulated mass of trade practices, business methods, and usages built up through the years, there was injected, even up to the beginning of our present century little knowledge derived from pure scientific research into wood products and the wood products industries. However, by that time certain forces were well under way that were destined shortly to produce results and create an entirely new factor in the field of wood-using trade methods of America, and other countries also.

A perusal of the above masterly synopsis will do much to dissipate the general idea that once a tree is felled it is simply a question as between the log-hauler, saw-miller, transporter, and the consumer to complete satisfactorily the cycle of operations making the timber fit for its purpose. The next chapters will show how diverse and how far-reaching scientific research has to be in order to make this cycle an economical as well as a satisfactory one.

III. THE SCIENTIFIC UTILIZATION OF FOREST PRODUCTS.

Australia has been fortunate in having had at its disposal a large number, and comparatively large quantities, of exceptional quality hardwoods and also slow-growing conifers of very good quality, too. Largely rule of thumb experience has laid down that certain hardwoods are suitable for one purpose and others for another ; similar rough and ready methods have decided that other hardwoods, because of certain defects, are not fit for use either, at all, or for special purposes. In this way there has been an exceptional demand for some hardwoods which, in some cases, has exceeded the normal supply, with the inevitable corollary that the supply is diminishing and is leading to the rapid extinction of many a species of timber. The demand for conifers has been universally in excess of the normal supply. Notable examples are, the hoop pine of Queensland, of which there remains roughly twelve years' supply, various indigenous pines of Tasmania, and such timbers as the tallow wood of New South Wales and the turpentine of New South Wales, and silky oak of Queensland ; among other hardwoods, the red cedar of Queensland, the blue gum and blackwood of Tasmania, and the mountain ash of Victoria should also be mentioned, while the jarrah and karri forests of Western Australia will inevitably cease to exist as important sources of timber supply within a generation from now unless the annual cut is limited very soon to the scientifically calculated supply available. In Australia, overcutting generally is the rule rather than the exception, and consequently the approaching crisis is very real and urgent, for it strikes at the very root of the nation's existence.

It is thus quite clear that scientific forestry and scientific research into forest utilization must start work hand in hand at once to bring about a more stable state of affairs. Scientific forestry will assure to the consumer a steady supply of the forest products required, while scientific research into forest utilization will help to eliminate waste, insure that the forests products reach the consumer in the best marketable form, and that as many forest products as possible are put on to the market as demands arise or are developed. It is useless for an expanding country like Australia to look for a permanent supply of forest products, that is mainly timber, from overseas. Practically every country in the world is faced with the problem of conserving its own timber resources and making as economical use as possible of available supplies or of increasing them. Consequently, the details that follow are simply the logical outcome of a review of Australia's problems in forestry with special reference to forest utilization.

(*a*) Timber Seasoning.

Nearly one-half of the timber cut annually is for structural use. The use of green timber for this purpose is unsound, and hence the question of timber seasoning is perhaps the most important problem in forest utilization awaiting scientific solution in Australia to-day; for apart from the fact that green timber is liable to insect and fungus attack, to warping, checking and cracking, the use of such timber in structural work involves the use of timber of heavier section than in the case of seasoned timber, because of the lower mechanical strength of the former, which, of course, is uneconomical. This is amply borne out by actual tests made in Australia and elsewhere, and when it is realized that a saving of 25 per cent. or more in the amount of timber used can be at once attained by the utilization of properly seasoned timber, the importance of the matter becomes still more apparent.

In the case of the larger timber concerns supplying the cities and towns of Australia and meeting the overseas demand, the matter has received attention, and the proper stacking of timber in the open and under cover and air-seasoning it up to a period of two years is largely practised by such concerns. The monetary loss involved to the country, however, in tying up capital in this way is very great. One timber yard visited by me had over 12 million feet super. in stock and had to hold this stock for two years before realizing its value at, say, 30s. per hundred super. feet, or £180,000 sterling.

At a low estimate not less than 200 million feet super. of hardwoods are being air-seasoned annually in Australia; and, calculated as above, the capital tied up would be no less than £3,000,000. This is where artificial seasoning methods, ordinarily known as kiln seasoning, have their great advantage, for a preliminary short period of air-seasoning, followed by a still shorter period of artificial seasoning, covering in all a period of from six to twelve weeks, will, in skilled hands and with the proper type of kiln, and adequate temperature, moisture and ventilation controls, do the work which natural methods can only accomplish in 24 months, or eight times as long. The saving to the timber industry in general and to the consumer in particular is thus very considerable.

So far scientific research into artificial seasoning methods has been carried out principally in Western Australia by the Forests Department; in South Australia by private agency; in Victoria by private agency, the Forests Commission, and the Defence authorities; and in New South Wales by private agency. Originally, experimental work was based largely on the methods advocated by Mr. H. Tiemann, United States of America, after a personal visit to Australia a few years ago, and later, modifications and developments were introduced to meet local difficulties. The result has been the patenting of half a dozen methods or more, all of which have their good points, but which are not all based on either a comprehensive or deeply scientific preliminary study of the factors involved.

The whole subject of artificial seasoning requires thorough scientific investigation, involving much experimental work and labour. No two species of hardwoods or even softwoods are likely to respond to the same schedule of treatment, and it may be assumed straight away that every timber species in Australia will have to have its artificial seasoning method worked out. Combined with the study of the factors directly influencing artificial seasoning should be a careful investigation of the micro-structure of the timber concerned, and with this must be taken into consideration the forest conditions under which the particular timber has been grown. The last point will be referred to again when the question of timber-testing comes under review. But as the solution of problems such as the "brash" fracture of the heartwood timber of some eucalypts, with the consequent rejection and waste of the centres of each log, the existence of "pipes," the exact age at which a tree's timber becomes "mature" for all practical purposes, and the variations in strength and behaviour of timber from different parts of the same tree, depends on the determination of the relative values of these factors and the bearing of each on the problem as a whole, the study of timber physics is evidently as important as the study of the narrower field of timber mechanics.

It is well within the realm of possibility that research into the factors of the rate of growth of the young eucalypt, in other words the density of the crop in the early stages of development of the tree, will have far-reaching results on the baffling problem of the deterioration of the heart-wood timber, though bush fires alone might account for this, in part or in whole. Again, though several attempts have been made, no really satisfactory key to the Australian hardwoods, based on the micro-characteristics of their wood, has come to my notice, or is, I believe, in existence.

There appears to be little doubt that the interest alone on the capital now tied up in the air-seasoning of Australian hardwoods will fully meet the cost of building artificial seasoning kilns at the principal centres of consumption in Australia, once intensive and centralized scientific investigation has shown how this can be done efficiently and economically. At present the cost of artificial seasoning, owing to the small scale on which it is practised, is high, and, besides, prejudice against the method is strong and is partly justified by the uneven results obtained in the past, which in its turn is due to faulty lines of investigation and application of methods based on unsound or insufficiently studied principles.

The work to be done has to be done well, and therefore has to be carried out by experts with long years of experience behind them. While such experts are at work, Australian research workers can be learning, and after three or four years will be fully equipped to carry on. This policy has been pursued in India with signal success.

The policy obviously involves centralized research work, to which, as regards timber seasoning research, exception may be taken on the grounds of the influence of varying climatic conditions under which the timber will be used. This influence, however, is not likely to prove important, as research principally in America has established the existence of a point, now called the "fibre saturation point," beyond which the amount of moisture does not affect either the strength or shrinkage of timber. This basic information (*vide* "The Decennial Record of the Forest Products Laboratory, Madison, Wisconsin, United States of America, 1921") is now in constant use in all studies of the mechanical and physical properties of wood.

(*b*) Timber Testing.

Before the problem of selecting Australian woods suitable for specific purposes can be solved, a very careful and detailed investigation into the physical characteristics of Australian timbers has to be gone into. Considerable, and in some cases, notable work has been done in investigating the mechanical properties of certain Australian woods by various workers. The most thoughtful of the papers I have seen is that by Mr. J. M. West, B.Ag.Sc., A.A.C.I., issued departmentally as "Technical Paper No. 21," by the Department of Defence, Commonwealth Government of Australia, in September, 1924.

Mr. West, in his paper, commented on the absence of any reliable comparative data on Australian timbers, particularly in connexion with their physical and mechanical properties. He, therefore, gave considerable attention to finding suitable means for collecting and recording information according to a systematic plan, so that the results obtained would be comparable and would be available as a basis for sound judgment on the relative merits of timbers for given purposes. He goes on to say—"The principle involved is universally accepted, is applied in practice in the United States of America, and is being adopted in Britain and other countries. It is considered essential that a similar plan of investigation be adopted in Australia for the control and guidance of the industries which will be depended upon to fill requirements." He continues—"The scheme outlined for determining the physical characteristics of Australian timbers is along the lines laid down by the Forest Products Laboratory, Madison, United States of America, as set out in the tentative standards of the American Society for Testing Materials, 1923." The paper setting out those tentative standards is, in my opinion, of such importance that it is reproduced at the end of my report as Appendix III.*

Mr. West's paper only deals with the investigation of the physical characteristics of Australian timbers, but other aspects of the problem are correctly indicated by him as being the study of economical methods of seasoning already referred to by me in Section III. (*a*), and methods of preservation of timber which forms Section III. (*c*) of my report. As already stated, Appendix III. describes, in full, the provisional scheme of testing small, clear specimens of timber as applied in America and other countries, and I agree with Mr. West that this scheme in its standard form is eminently suitable for adoption in Australia. He continues his cogent remarks on the subject as follows :—

> To carry out satisfactorily the necessary programme, provision is required for :—
>
> Selection and felling of trees.
> Transport of logs.
> Breaking down logs.
> Preparation of test pieces.
> Testing of green and air-seasoned specimens.
>
> No Federal or State Department has the organization and equipment necessary for the work. It is feasible, though inconvenient, to organize and carry out a programme on the above lines by co-ordination of existing facilities, provided that one of the co-ordinating Departments is in a position to undertake the supervision of the work and suitable arrangements as to the provision of funds can be made.

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* The printing of this Appendix in this present publication has been considered unnecessary.

A possible allotment of the work among the various Departments is as follows :—

The State Forestry Commissions at present are able to supply timber for testing, and have the necessary staff and organizations to provide for the selection, felling, and transport of logs. Logs can be broken down and test pieces prepared in either private or Government mills and woodworking shops. The equipment installed at the Research Laboratories, Maribyrnong, and the S.A.A.F.* is suitable for carrying out most of the chemical and physical tests, the only additional plant required being an impact machine (Hatt-Turner type) and a number of special timber-testing grips and tools.

The computing, analyzing, and recording of the results involves a large amount of work and could be carried out by a special staff attached to the Research Laboratories, or the timber investigation section of the Institute of Science and Industry,† or other body.

Any project carried out on the above lines, to be successful, must be directed and supervised by one of the co-operating institutions."

These remarks indicate the necessity for centralizing this type of work, and a reference to Appendix III. shows what very responsible work devolves on the Forestry Departments in the selection and transportation of timber for testing. At present, as already stated, timber-testing of different degrees of intensity is carried out at many centres in Australia. It is not surprising, however, that a defective bibliography on the subject and lack of co-operation between the departments or bodies concerned led to the production of a mass of data which are not as valuable as they might have been.

The inauguration of a programme of research into timber physics on a comprehensive scale in Australia is of paramount importance, not only in order to utilize to the fullest extent the timbers of the country, but also to make it possible to formulate grading rules for the utilization of the timbers and the compilation of tables of working stresses, both of which are likely to result in considerable economy and savings in structural works. Anything that tends to the more economical use of timbers on account of definite data of strength, &c., being made available for the use of the architect, the engineer, and municipal authorities and other bodies, and the possibility of using the lower grades of timber for purposes such as wall joists, where the stiffness rather than the strength of the timber is the principal consideration, is a matter of public importance and will justify a considerable outlay on centralized research in order to attain these objects. (For a fuller exposition of the matter, see pages 15–16 of the *Development of India's Forest Resources*—Government of India Central Publication Branch—1923, to which publication I am indebted for a summary of the relevant arguments). The work done at the Forest Products Laboratory, Madison, United States of America, and the Forest Research Institute, Dehra Dun, U.P., India, amply bears out this contention.

A great necessity in Australia to-day is the cheapening of the cost of the construction of homes and the above scientific inquiry will have a direct and favorable bearing on the question.

Timber testing is not, however, restricted to the testing of structural timber. Definite and detailed knowledge of the mechanical properties of different woods makes it possible to effect savings in the construction of fruit-boxes, butter-boxes, crates, and shipping containers of various kinds. These forms of utilization account for a very considerable proportion of

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* Small Arms Ammunition Factory, Footscray, Melbourne.
† Now the Council for Scientific and Industrial Research.

the total consumption of timber in most countries, and in Australia will probably represent more than the average because of her large and expanding primary industries, such as fruit-growing, dairying produce, and so forth. Well-considered designs, having due regard to the proper balance of a container, often lead to savings in the dimensions of the various wooden parts which would, in the aggregate, result in the use of as much as 25 to 50 per cent. less timber, according to American figures. To illustrate further the extent of the field of research in timber-testing, I again quote from the Decennial Record of the Forest Products Laboratory, Madison, United States of America, as follows :—

> Other profitable fields are those involving the development of built-up trusses, thus making possible the utilization of low grade lumber; the development of joints and fastenings in timber construction ; the effect of growth conditions on the properties of wood, and especially the determination of the differences in the mechanical properties of the second growth timber now coming to merchantable size, and upon which the industries will be more and more dependent ; the development of laminated construction permitting greater utilization of small-sized and low-grade material; comprehensive tests on full-sized timbers used as columns for building construction ; the standardization of building codes so that each species will be given its proper place, based upon its true mechanical value, thus avoiding the large waste now resulting from the inefficient selection and utilization of material.

(c) Timber Preservation.

With the possible exception of the havoc caused to timber by forest fires, the decay and destruction of timber by reason of fungus, insect, and marine borer attacks, probably accounts for the largest items of preventable waste in the timber bill of any country. Were scientific research, by means of chemical timber preservation, able to prolong the life of Australia's railway sleepers, mine timbers, wharf and bridge piling, bridge timbers, posts, poles, &c., even by a year or two, the total annual saving to the country would run into a very large figure indeed.

But that is only one side of the case. The preservative treatment of timber would result in the utilization of species of wood which are at present not durable in contact with soil, water, &c. Not only would this lead to a greater use of Australia's forest resources, but it would liberate many a fine hardwood, such as jarrah, for its legitimate use as one of the best structural and cabinet woods in the world and save it from its present ignominious utilization as railway sleepers in Australia and overseas ; a truly short-sighted policy, for timbers of the quality of jarrah are not many in the world, and the quantity available is limited. The change cannot be effected in a day because of the trade interests involved, but it should be borne in mind and brought into effect as soon as possible. The task will be a fairly easy one, for Australia now fully realizes her weakness in regard to softwood supplies, with the result that plantations of suitable pines are springing up in nearly every State with a rapidity which is all to the credit of the more far-seeing forestry authorities concerned. Those pine plantations, combined with proper systems of preservative treatment of their timber, will give to Australia an ever-increasing supply of pit-props, posts, poles, and railway sleepers, for which at present valuable hardwoods are employed.

With the exception of Western Australia, where the Powellizing system of timber preservation has been practised for many years, very little has been done in this line of research, though some experiments in creosoting sleepers carried out at the University of Adelaide deserve mention. The field of research is again a wide one, and a properly equipped timber preservation laboratory, fitted with open tanks and also modern pressure cylinders, so devised as to obtain full control of temperature, vacuum, and pressure will, in the course of a year or two, indicate the best systems of timber preservation for the numerous species of Australian hardwoods and softwoods requiring investigation. Here, as in the case of timber seasoning, it is more than probable that every timber will require its own definite schedule of preservative treatment worked out. And here, again, the work is work for experts having years of experience behind them.

In the matter of preservative agents Australia appears to be favorably situated, for in its coal mines and gasworks it has a large potential supply of the universal preservative for timber, namely, creosote. The Forests Department in Western Australia is just putting into commercial application a new system of boiling timber by the open-tank method in a solution in which sodium fluoride and arsenic are the principal ingredients. The system has been patented under the name of "fluarizing," and has every prospect of success in localities not subject to excessive rainfall.

Once scientific research has demonstrated the applicability of any preservative treatment the next step is experiments on a semi-commercial scale, and the final stage is its application as a commercial proposition. Close co-operation between the scientific worker and the consumer, principally the railways, throughout the duration of the work is an important factor in success. In this way, in the course of a few years, Australia will be in a position to fight that great source of waste in her timber utilization, namely, natural decay of timber.

(*d*) Wood Pulp and Paper.

The feasibility of manufacturing pulp and paper from Australian woods has been a matter of considerable research in Australia, and forms the subject of the Institute of Science and Industry's Bulletin No. 19 of 1921, "Wood Waste," by Mr. I. H. Boas, M.Sc.; of the same Institute's Bulletin No. 25 of 1923, "The Manufacture of Pulp and Paper from Australian Woods," by L. R. Benjamin; of the Council for Scientific and Industrial Research's Bulletin No. 31 of 1927, "Newsprint," by the same author; while an account is also given on pages 22 and 23 of the *Journal of the Council for Scientific and Industrial Research* for August, 1927 (Vol. 1, No. 1) regarding what has been done up to that date.

Laboratory experiments have been successful, and it is not unlikely that the manufacture of paper from young eucalypts in Tasmania will take commercial shape within a year or two, while the experimental manufacture of kraft paper on a semi-commercial scale from the young timber of the Monterey pine, also known as *Pinus insignis* or *radiata*, in specially designed plant, erected by Mr. L. R. Benjamin under the auspices of the Council for Scientific and Industrial Research, in a Sydney paper-mill, is likely to be a success. Should this prove to be the case there will be a market for the thinning wood from the many thousands of acres of plantations of *Pinus insignis* and other planted pines in South Australia and elsewhere. The scientific experimental work so well begun has to be continued, for so far only a very few species of timber, comparatively speaking, have been tested, while the number available is very large. Again, experiments have borne only on the timber from trees, while the waste from the saw-mills has not been studied at all. When it is realized that under methods of conversion as practised in Australia, barely 40 per cent. of the tree reaches the consumer after it has passed through the saw-mill process, the necessity for finding a use for this great source of waste now burnt on the mill's fire chutes is readily understandable.

Australia consumes a great deal of paper, and if even a part of the imported quantity is manufactured in Australia itself the economic benefits to the country will be considerable. Scientific research in the past has solved the problem in part; there is no reason to doubt that scientific research in the future will solve the problem in whole.

(*e*) Tanning Materials.

Research into tanning materials has been the subject of closer scientific work perhaps than on any other forest product in Australia. For this, the country is indebted to the Council for Scientific and Industrial Research, and their Bulletin No. 32, "A Survey of the Tanning Materials of Australia," by D. Coghill, 1927, gives a most interesting account of what has been done.

Australia possesses a large quantity of trees yielding barks rich in tannin. The scattered distribution of the trees caused the cost of collection in some cases to be too high to be able to compete in the world's markets, with the result that the black wattle industry in the course of years was gradually transferred from Australia to South Africa, with the rather peculiar further result that Australia is importing black wattle bark from South Africa to meet her own requirements. Similarly, the demand for mallet bark from Western Australia led to the virtual extermination of this species of eucalypt, with the result that in a few years' time the value of this export industry dwindled from £150,000 a year to a bare £15,000. The Western Australian forestry authorities have now taken the matter up, and in the course of time concentrated plantations of mallet will, it is hoped, restore to that State this profitable industry.

Combined with the production of tanning bark, is the question of the preparation of tannin extracts. Here again the Council for Scientific and Industrial Research is to be congratulated on its progressive policy, for an up-to-date tannin extract plant on a semi-commercial scale is in course of erection in the grounds of the University of Perth, Western Australia, which on completion will be devoted to the study of tannin extracts from various eucalypt barks and the barks of other species of trees. A promising local source of supply of raw material is the waste bark from the logs in the saw-mills utilizing karri timber. Another possible source is the waste bark after the fibre has been extracted from certain stringy barks in Victoria, where in Melbourne a company is already in being for extracting such fibre for upholstery and so on.

From the foregoing it may be concluded that this realm of forest utilization research is safely launched. All that is required in the future is to continue the research until every economic source of supply in Australia has been tested out in regard to its commercial possibilities. Provided the price is right, the world's markets will be able to absorb the supply.

The cost of collection of the raw material is perhaps the most difficult of the problems awaiting solution. It is here that the Forestry Departments can assist. To cheapen the cost of collection the tanning bark-producing trees must be grown in concentrated form, that is to say, in plantations, and barking machinery must be employed. As regards the latter there are already suitable, easily portable machines on the market, and they are being employed with success in the States of South Australia and Victoria.

(*f*) Oil.

Until recently, Australia held a monopoly in the production of one series of oils, namely, eucalyptus oils, but in recent years competition has arisen in India, South Africa, and, I believe, in California. Considerable research work has been done in Australia on the subject of the distillation of eucalyptus oil and the commercial constituents of these oils, the publication of Messrs. Baker and Smith being the most notable on the subject, while excellent work is being done in the laboratory of the Technological Museum in Sydney, New South Wales, by Mr. Penfold and his assistants. The Forests Commission in Victoria has an eucalyptus oil-distillation plant at Wellsford, near Bendigo, and this venture is proving a profitable investment.

Future research appears to lie in solving the problems of efficient and cheap distillation on a commercial scale, the isolation in the crude oil of fractions or constituents of special value in chemical industries, and a further study of the possibility of the economical preparation of synthetics such as menthol and thymol, &c., from the oil or its fractions.

Eugenol has been obtained by the steam distillation of chips of wood of the Huon pine of Tasmania, and experimental work on this subject has been done by Messrs. Baker and Smith and published in their book on the indigenous pines of Australia. The matter appears to be of academic value only, as the quantity of Huon pine timber available is not very large, but as eugenol may be a base for synthetic vanillin, it may be worth considering further.

But both in value and importance the distillation of sandalwood oil from the sandalwood tree of Western Australia and the western border of South Australia is by far the most important oil industry connected with a forest product in Australia. The wood is being distilled for its oil on a large scale by a private firm in Perth, Western Australia, and though the oil is chemically and physically different from the Indian sandalwood oil, therapeutically it is said to be identical. A large quantity of the oil is used in the perfumery and toilet soap industries.

In the time at my disposal I was not able to make further inquiries into possible sources of essential, edible, and other oil supplies from forest trees, &c.. and this will be an investigation which will require the close attention of the minor forest products section of the Forest Products Laboratory, Australia, when created.

(g) Fibres, Resins, and Other Minor Forest Produce.

Lack of time made it impossible for me to carry out any detailed investigation into the field of minor forest products such as fibres, resins, and so forth.

The enterprise of a Melbourne firm in starting a factory for the extraction of the fibre from the bark of various stringybark eucalypts has already been mentioned. The fibre appears to be a fair substitute for coir and is being used for upholstery and so on.

Those interesting trees the black boy (*Xanthorrhoea* species) and the grass tree (*Kingia* species) which, at first sight, would appear to be quite useless, are potential sources of supply of a resin and coarse fibre which have been exploited to some extent, but require further investigation and propaganda work to get them used more extensively in the industries of Australia.

It has been the experience in forest products laboratories elsewhere in the world that inquiries and subjects for investigation spring up with astonishing rapidity after the creation of such laboratories. In India, the economic branch of the Forest Research Institute began work with one section only, but not many years elapsed before it was necessary to have a whole-time officer for investigating minor forest products. This will no doubt be also the case in Australia. Such industrial ventures as the preparation of power alcohol from wood and sawdust (see Bulletin No. 33 of the Council for Scientific and Industrial Research, "The Possibilities of Power Alcohol and Certain Other Fuels in Australia," by Mr. G. A. Cook, M.Sc., B.M.E., 1927) and the use of charcoal for making gas in producer gas-plants for internal combustion engines are only two of many such matters which should be taken up as opportunity offers.

(h) The Scientific Utilization of Lumber.

The concluding remarks of the preceding paragraph apply still more cogently to what I have entitled the scientific utilization of lumber. A wide subject, covering such questions as the proper season for felling the tree, the best methods of handling the logs, the most efficient methods of cutting up the logs, the utilization of the timber in the veneer, three-ply, turnery and cooperage industries with all their ramifications, the study of the derived products of wood, and industrial investigations in manufactories employing timber, which may be grouped under the head of the technical study of the efficiency of wood conversion processes. A vast field indeed, where activities are limited solely by the adequacy of the organization set up for its disposal.

The secondary wood-using industries alone consume a large quantity of timber annually, and, as in America, the study of the dimension-stock problem may have far-reaching results. The present practice in Australia is to cut up the logs in small mills close to the forests into more or less standard timber sizes and to send the latter to centres where the wood using factories, &c., are situated. There the timber is again cut up to its ultimate required dimensions. The waste is obviously enormous. To illustrate the point: a considerable amount of timber is required for bending purposes in the construction of motor bodies and agricultural machinery. The timber to be used economically has to be cut tangentially. Now, were that timber required for furniture or joinery work, the timber would have to be cut radially, that is, on the quarter. The problem will require long and accurate studies to determine the most efficient processes by which the standing tree can be converted into the dimension standards required by the wood-using industries. Until this problem has been seriously tackled it appears to be wise to restrict the activities of the bush mills to the cutting of large flitches of timber, known sometimes as "junk" timber, to transport these to centres of consumption and have them there cut up by the wood-using industries concerned to meet specialized requirements.

It is difficult to estimate the saving to Australia by the adoption of such methods, but the opinion may safely be expressed that in the aggregate the saving annually will pay for the personnel of the projected forest products laboratory for Australia many times over.

IV. ORGANIZATION OF THE PROPOSED FOREST PRODUCTS LABORATORY.

A perusal of the preceding sections will have shown the close connexion throughout in the work of the Forestry Departments in Australia and the proposed Forest Products Laboratory. That such a laboratory is necessary is clearly established, it is held, by the arguments contained in my Report. No progress can be expected in the development and full realization of the value of Australia's forest estate except by close research in a laboratory fully equipped for the purpose. In order to get results quickly, and also in order to eliminate that costly method of getting results of sorts by a process of trial and error, I have indicated on more than one occasion in the Report that the work to be done is largely work for experts. Once these experts have started and thoroughly organized research in their respective branches, the Australian research workers who have been trained in the meantime will be able to take up the research and bring it to successful fruition. It follows that research into forest products will have to be centralized in order to obtain the best results from the employment of experts. If this argument is accepted the locality for the proposed Forest Products Laboratory for Australia will be Canberra, the Federal Capital, where there is already a Forestry School teaching forestry to Australian students from all the States. Land is available in the plantations around the Forestry School, and the possible sites have been seen by me.

As regards organization, I hold that as it is impossible to dissociate advanced forestry from advanced utilization, and as all the forests of Australia are the property of the Crown and are being worked either by the State or by timber concerns on leases, licences, and permits, the administrative authority over the forest products laboratory should be combined in one and the same person or Department as that having administrative authority over the Forestry School and the proposed Forestry Bureau, regarding which a Bill is now before the Federal Houses of Parliament. A chart showing my tentative ideas on the subject of a suitable organization forms Appendix IV. to this Report.

Centralization of forest products research will enable all work of this nature, now going on in the States, to be closed down, and it may be possible to make use not only of the equipment thus liberated, but also of some of the staff, if considered qualified. Once the organization of the Forest Products Laboratory is in full working order I consider that all such work elsewhere in Australia must be closed down. Any other course means loss of energy, time, and money.

Centralization of forest products research may meet with some opposition in the States, for the argument has already been advanced that the Federal Capital Territory is so remote from some of the States that their problems will not receive adequate attention. This will not be the case. A reference to the chart will show that the advisory functions of the Inspector-General of Forests in regard to State forestry may be considerably developed should the States so wish it. In my opinion, the States would be ill-advised to refuse such assistance. In India close co-operation between the Government of India and the Provinces in their forest policy has resulted in the formation of a forest estate second to none in the British Empire. There is no reason why Australia should not follow suit.

As regards the actual programme of research work to be taken up at the Forest Products Laboratory, I suggest the adoption of the plan followed in India, namely, that a Board of Forestry should be formed and meet triennially in order to decide on the triennial programme of research to be carried out at Canberra. The Board should consist of the head of each State Forestry Department, a member of the Council for Scientific and Industrial Research, and representatives of the timber industries, limited to one for each State. The Inspector-General of Forests to the Commonwealth Government of Australia would be *ex-officio* Chairman, with the Director of the Forest Products Laboratory as Secretary.

The gross revenue of the Forest Departments in Australia is nearing the £1,000,000 mark. When the full 24,500,000 acres of forest land has been dedicated as permanent State forests, and is worked on scientific principles, the revenue will increase at least tenfold. This figure is significant and should be borne in mind when the question of costs is discussed in the next section.

V. COST OF THE PROPOSED FOREST PRODUCTS LABORATORY.

Only very rough figures can be given in regard to the capital cost of building and equipping a Forest Products Laboratory. The design of the building should be strictly utilitarian, and I suggest that the Defence Laboratories at Maribyrnong, Victoria, may be accepted as suitable in regard to architectural and engineering design. I propose to give only the plinth or superficial area required by each section or branch of the Forest Products Laboratory. For the Timber Testing Section an area of 100 feet x 40 feet, i.e., 4,000 square feet, should prove adequate.

The Timber Seasoning Section will require the same area to start with, namely, 4,000 square feet. Timber Preservation can do with a little less, and an allowance of 3,000 square feet should prove ample. The Timber Utilization Branch will comprise the necessary offices, records room, and sectional library with an allowance of 3,000 square feet should suffice to start with. The Chemical and Minor Forest Products Section (which also includes provision for a Forest Products Museum, if the Forestry School cannot house it) can also be accommodated in 3,000 square feet of area. That makes in all 17,000 square feet. The buildings need not have a clear height of more than 15 feet. Allowing £1 per square foot, the main buildings of the Forests Products Laboratory would cost £17,000. In addition, outhouses and store sheds for timber, for stores, &c., built in a cheap way, will take some 8,000 square feet, which at 10s. per square foot would cost £4,000.

The total cost of the buildings would, therefore, be £21,000 or, allowing for contingencies such as the laying out of the grounds of the laboratory, the roads, and the necessary connexions for gas, electricity, water, and sewerage, say, £25,000.

The question of the cost of equipment is also difficult, because I have no data of the actual cost of machinery, chemicals, and so forth in Australia. Besides, as stated in the preceding section, a certain amount of equipment may be available secondhand by reason of the closing down of institutions, in part or in whole, where investigations into forest products are now being carried out. In giving the figures I also assume that the tannin extract plant just completed in the grounds of the University of Western Australia will remain there for the time being.

The most expensive part of the equipment of the Forest Products Laboratory will be the Timber Testing and Timber Physics Branch. I have allowed a lump sum of £8,000 for the purpose, which figure is based on some data obtained from the Defence Laboratories near Melbourne. Timber seasoning, too, is costly; but, to start with, the battery of kilns required should not cost more than £3,000. The equipping of the Timber Preservation Section will cost £5,000, based on the experience of the Forest Research Institute, Dehra Dun, India. The Utilization Branch should not cost very much, and to start with £1,500 should meet the cost. The Chemistry and Minor Products Branch may cost up to £3,000 to equip. Gas, electricity, water, and miscellaneous permanent fittings may be put at another £2,000, making a total of £22,500. Allowing £1,500 for contingencies and unforeseen items, the total cost will come to £24,000; that is to say, the whole capital cost will be £49,000.

The next question to be considered is that of the personnel. To start with, experts from abroad will be required to take charge of the branches of Timber Testing, Timber Seasoning, and Timber Preservation, on short agreements of, say, three years, on terms to be arranged.

My estimate of the cost of the personnel is based on the rates of pay to be given when the whole staff is recruited in Australia. The list is as follows:—

One Director of the Forest Products Laboratory, at £1,200 per annum	£1,200
One Officer in Charge, Timber Testing, at £800 per annum	800
Two Assistants, at £400 per annum each	800
One Mechanic, at £300 per annum	300
One Carpenter, at £300 per annum	300
One Officer in Charge, Timber Seasoning, at £800 per annum	800
One Mechanic, at £300 per annum	300
One Officer in Charge, Timber Preservation, at £800 per annum	800
One Assistant, at £400 per annum	400
One Mechanic, at £300 per annum	300
One Chief Clerk, at £500 per annum	500
Two Computors, at £450 per annum	900
One Filing Clerk, at £400 per annum	400
Two Typists, at £250 per annum each	500
One Chemist, at £600 per annum	600
One Laboratory Assistant, at £400 per annum ..	400
One Museum Curator and Librarian, at £500 per annum	500
Two Handy Men, at £300 per annum each	600
Per annum	£10,400

The annual maintenance of grounds, buildings, and plant may cost £3,000. The cost of chemicals, creosote, stores, &c. annually may be put at about £1,500. The library and museum and office maintenance charges are estimated at £1,000. Travelling and other allowances of staff are estimated at £1,500, while contingencies may absorb £1,600, or a total for personnel and maintenance of £19,000 per annum. If the housing of the staff has to be undertaken by Government the estimates have to be increased to meet such cost. But as rent for the houses will be recovered, it is open to question whether this head of expenditure should be debited to the capital cost of the project.

It is held that at the cost specified, or even at a cost considerably in excess, the project is worth inaugurating, because of the many benefits which will result to Australia.

VI. CONCLUSION.

What remains to be said can be said in a few words. It is my firm conviction that Australia and Australians are destined to take a high place in the development of the British Empire. If they do not, it will not be the fault of the country and its vast actual and potential wealth, in which Australian forests is a significant item. If they do, her forests and the role to be played by her forests in this development will be appreciated at their right value. There is already a strong current of public opinion in favour of a more progressive forest policy, in which policy the fighting and prevention of bush fires is definitely the most important step. Public consciousness is also awakening to the fact that all is not well in regard to Australia's future timber supplies. My report and the experience of scientific workers in forest utilization throughout the world show what has to be done. The doing of it, however, is the duty and responsibility of the representatives of the people, Australia's legislators.

APPENDIX I.

DETAILS OF TOURS.

(12th July to 10th December, 1927.)

12th July	Made over charge of my duties under the Government of India in the afternoon.
13th to 23rd July ..	Preparation and in transit to Colombo.
24th July to 1st August	In transit—Colombo to Fremantle.
2nd to 12th August	In transit by sea via Adelaide, Melbourne to Sydney, meeting forest officers and officers of the Council for Scientific and Industrial Research at the ports.
13th August ..	Sydney—visited Technological Museum.
14th to 16th August	Sydney to Canberra and back to see the Inspector-General of Forests and inspect Forestry School, &c.
17th August ..	Round Sydney—saw types of forests.
18th and 19th August	Sydney to Brisbane.
20th to 25th August	In Brisbane, seeing local forest industries and institutions, meeting forest officers and officials of the State Committee of the Council for Scientific and Industrial Research.
26th to 31st August	A motor tour via Yarraman and Maryborough to see hoop pine forests and mills, with a trip to Fraser Island and back to see forest types.
1st September ..	In Brisbane, interviews with State officials, &c.
2nd to 7th September	A motor tour along the north coastal region of New South Wales to see forest types and forest industries.
8th to 11th September	Rail and motor tour round Narrabri, New South Wales, to see forest types and industries.
12th to 16th September	In Sydney, visiting many industries consuming wood. By rail to Melbourne on evening of 16th September.
17th September ..	Reached Melbourne.
18th to 20th September	In Melbourne, visiting State Forestry officials, and working in the offices of the Council for Scientific and Industrial Research.
21st September ..	Left for Launceston, Tasmania.
22nd September to 5th October	An extensive tour in Tasmania, seeing all types of forests on the north, north-east, north-west, and west coasts, and part of the interior; also visited many industries, and seeing State Ministers and prominent officials.
6th October ..	Left Launceston for Melbourne.
7th October ..	Reached Melbourne. Worked in the offices of the Council for Scientific and Industrial Research.
8th to 10th October	In Melbourne and around, visiting forest types and industries.
11th to 12th October	A motor tour to the mountain ash areas around Warburton, and also the big saw-mills there, &c.
13th October ..	In Melbourne, seeing Defence Laboratories at Maribyrnong and Council for Scientific and Industrial Research Laboratories at Brunswick.
14th and 15th October	A motor tour from Melbourne to see plantation areas and Forest School at Creswick, and plantations at Anglesea.
16th October ..	A motor trip to Mount Macedon and back to see pine plantations.
17th and 18th October	In Melbourne, visiting industries and seeing prominent officials.
19th October ..	A motor trip to Powelltown and back to see forest types and large saw-mills, &c.
20th and 21st October	Motor tour and train journey to Bendigo and back to see forest types, eucalyptus oil industry, and other forest industries.
22nd October ..	In Melbourne, seeing local forest industries.
23rd October ..	Sunday—In Melbourne.
24th to 26th October	By train and car from Melbourne to Mount Gambier and Naracoorte, and on to Adelaide, seeing all the extensive pine plantations *en route*.
27th to 29th October	Visiting important forest industries in Adelaide and around, and also seeing forest types in the vicinity of Adelaide; also, seeing important members of the Government and officials.

APPENDIX I.—*continued.*

DETAILS OF TOURS—*continued.*

30th and 31st October	By trans-continental train from Adelaide to Kalgoorlie.
1st to 5th November	A tour from Kalgoorlie by car and rail, visiting typical forests, and seeing large saw-mills and other forest industries, reaching Perth on the afternoon of 5th.
6th November ..	From Perth, a motor trip to typical forest areas in the neighbourhood and back.
7th November ..	In Perth, visiting local forest industries.
8th to 13th November	An extensive car tour from Perth to Pemberton and back, seeing the valuable sub-coastal forests in this area.
14th November ..	Left Fremantle.
23rd November ..	Reached Colombo.
28th November ..	Reached Ranchi.
29th November to 10th December	Wrote my Report in Ranchi, and took over charge of my duties under the Government of India on the afternoon of the 10th December, 1927.

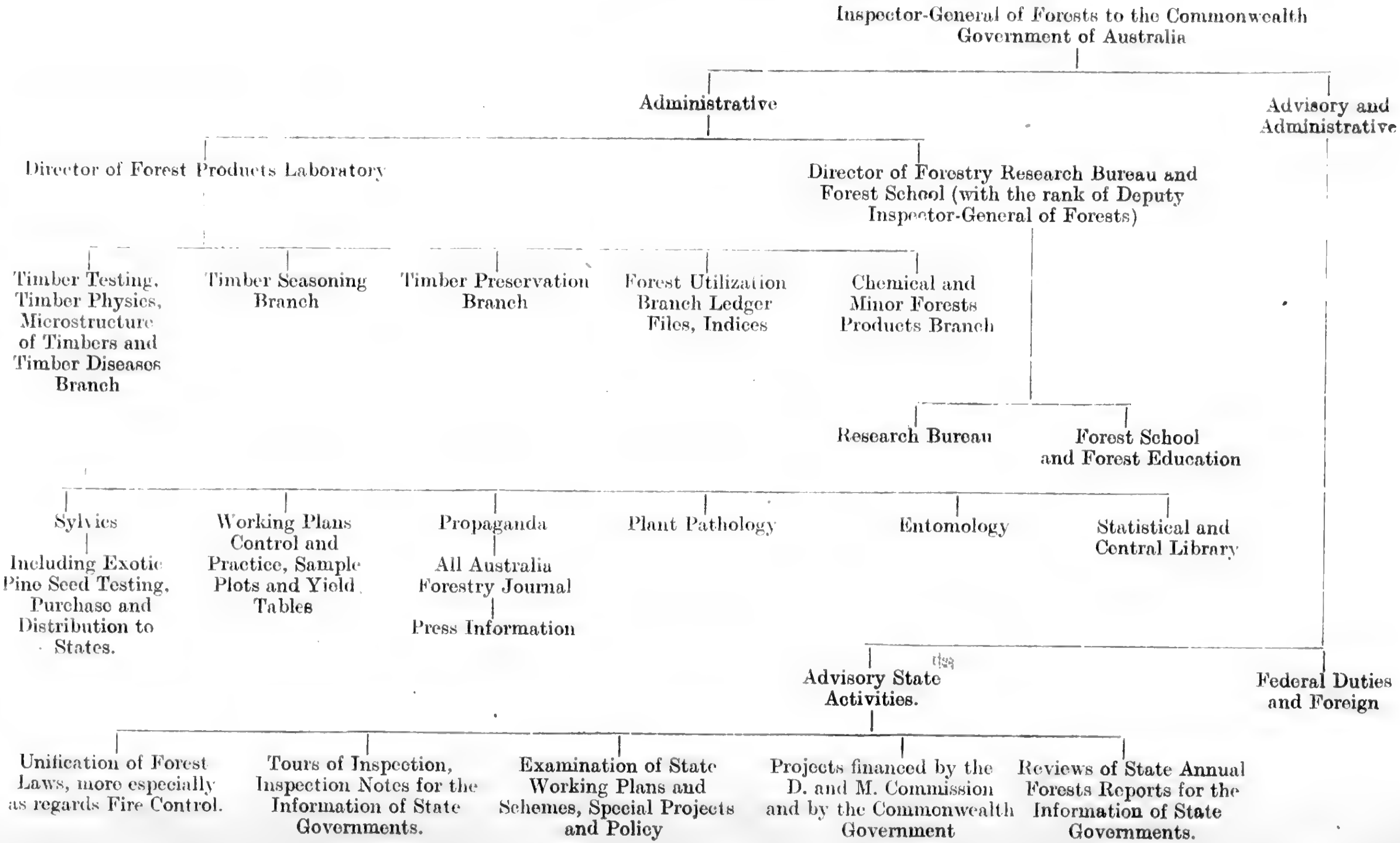
APPENDIX II.

State.	Lumbering and Forest Transport.	Saw-milling.	Air Seasoning.	Artificial Seasoning.	Joinery.	Furniture Making.	Box and Case Making.	Carriage and Motor Body Building.	Wooden Motor-wheel Making.	Timber Testing.	Technical Institutes and Laboratories.	University and other Educational Centres.	Veneer Cutting.	Three and Multiple Ply Cutting.	Sleeper Hewing and Sawing.	Turnery.	Timber Preservation.	Tanning Factories.	Fibre Making.	Producer Gas.	Paper and Pulp.	Oil Distillation.	Other Industries.	Totals.
Queensland	1	7	6	2	1	..	2	1	..	..	1	1	..	..	..	..	..	..	..	..	..	..	..	22
New South Wales ..	1	8	4	2	2	2	..	2	2	2	4	1	2	2	1	..	..	1	..	..	1	1	2	40
Victoria	2	6	7	6	4	1	1	..	..	..	2	2	1	1	..	..	..	..	1	..	..	1	2	37
Tasmania	..	..	..	1	..	1	..	..	..	..	1	..	..	..	..	1	..	..	..	..	..	..	1	5
South Australia ..	..	4	5	2	2	1	..	1	1	1	1	1	..	..	..	..	..	..	..	..	..	..	..	19
Western Australia ..	3	8	10	2	..	..	2	1	..	..	..	1	..	..	2	..	1	1	..	1	..	1	3	36
Federal	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	1
Totals	7	33	32	15	9	5	5	5	3	3	9	7	3	3	3	1	1	2	1	1	1	3	8	Grand Total 160

APPENDIX III.

[Not printed. See footnote in Section III (*b*).]

APPENDIX IV.



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COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

THE HEALTH AND NUTRITION OF ANIMALS

Reports by

SIR ARNOLD THEILER, K.C.M.G., D.Sc.,

AND

J. B. ORR, D.S.O., M.C., M.A., M.D., D.Sc.

MELBOURNE. 1929

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Council for Scientific and Industrial Research

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PAMPHLET No. 10

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PREFACE.

THE recent visits to Australia of Sir Arnold Theiler, late Director of Veterinary Education and Research, South Africa, and Dr. J. B. Orr, Director, Rowett Research Institute, Aberdeen, Scotland, were arranged largely as the result of representations made by Mr. G. A. Julius, Chairman of the Council, and Professor A. E. V. Richardson, at the time of the Imperial Agricultural Research Conference, October, 1927.

It was felt that the visits would be of value to Australia, not only by reason of the direct advice and inspiration that would result to her research workers, but also because both Dr. Orr and Sir Arnold Theiler would themselves become personally conversant with Australian problems, and this would render more valuable the help of the proposed new Imperial Bureaux of Animal Nutrition and of Animal Health, with which both visitors would probably be closely associated.

Sir Arnold Theiler was able to spend six months in Australia, but Dr. Orr's visit was more hurried. Both have furnished the Council with reports on the observations they made during their stay. These reports are printed on the pages that follow. In making them available, the Council desires to indicate that such action does not necessarily imply that the opinions expressed therein are its adopted views, nor that it is intended to follow in entirety the recommendations made.

CONTENTS.

A.—Report by Sir Arnold Theiler.

CONTENTS—*continued.*

CONTENTS—*continued.*

CONTENTS—*continued.*

B.—Memorandum by Dr. J. B. Orr.

INVESTIGATIONS INTO THE PROBLEMS OF ANIMAL HEALTH IN AUSTRALIA

BY

SIR ARNOLD THEILER, K.C.M.G.

I.—INTRODUCTION.

Investigations into the problems for research in animal health in Australia have been approached by me in a somewhat wider sense than is usually given in the interpretation of the term health. I consider health to be that condition of an animal which is the most suitable for maximum economic exploitation. This definition has accordingly a purely utilitarian aspect, but, as the principal object of research work from the point of view of the Council for Scientific and Industrial Research is to assist the primary industries, it served as my guide. A non-productive animal is apparently an unhealthy, or better, a diseased animal. The main object in studying diseases is to find their causes. Once they are found and can be explained, the question of prevention or cure is frequently solved at the same time, which means either removal of the cause or rendering the animal unsuitable for the development of the disease-causing agency. This is often possible in cases of infection due to micro-organisms.

The causes of diseases may be classified into three main groups :—

(*a*) Infections due to internal or external parasites, including diseases caused by viruses and micro-organisms, as well as those caused by visible parasites (worms, insects, mites, &c., &c.).

(*b*) Intoxications produced by saprophytic micro-organisms and by poisonous plants : mineral constituents of drinking water also come into consideration.

(*c*) Deficiencies caused by the absence of essential minerals and also by lack of necessary food constituents such as protein and accessory factors. The subject of deficiency is a wide one, and includes practically all aspects of nutrition. The standpoint from which I regard it is more particularly as a cause leading to unproductivity. Since it is sometimes associated with the problem of breeding of animals, reference to it will also have to be made.

The study of health requires also investigations into the normal conditions of animals, and in this respect I have found that certain features in connexion with sheep-breeding are only imperfectly known. I refer to the normal sexual cycle of the merino. It appears to me to be necessary to know more about this in order to understand certain phenomena of apparent sterility both in rams and ewes, particularly in the latter. It may simply be the result of mating at the wrong time or the result of pathological changes of the genital organs, or it may be the result of deficient nutrition or inherited organic malformation, and, as such, associated with some breeds. This will be referred to later in discussing the subject under the heading of the healthy animal.

II.—ITINERARY.

I left Basle on the 7th March, boarding the *Orama* at Naples on the 11th March. In Colombo I met Dr. J. B. Orr, Director of the Rowett Institute, Aberdeen, in whose company I proceeded to Fremantle, where we arrived on 3rd April and were met by representatives of the Council—Professor Wilsmore and Mr. G. L. Sutton—and were introduced to various members of the State Committee, Professors of the University, and officers of the Agricultural Department. We arrived on the 7th April in Adelaide, and were met by Professors A. E. V. Richardson and T. Brailsford Robertson. We paid a visit to the latter's laboratory at the University, and spent the afternoon at the Waite Agricultural Research Institute.

1. Visits in Victoria.

Arriving in Melbourne, we were met by Dr. A. C. D. Rivett, Mr. G. Lightfoot, Professor H. A. Woodruff, Mr. H. E. Albiston, Dr. Bordeaux, and Dr. W. A. N. Robertson. Melbourne was my head-quarters until 12th May. During this time I attended a full meeting of the Council for Scientific and Industrial Research, with Mr. G. A. Julius in the chair, and a meeting of the State Committee of the Council under Sir David Orme Masson. A visit was paid to the Research Division of the Veterinary School, and I was introduced to the various workers by Professor Woodruff. These gentlemen explained the different subjects on which they were working, and demonstrated such material as was available at the time. The investigations referred to were the Kimberley horse disease, by Mr. D. Murnane ; the black disease in sheep, by Mr. A. W. Turner ; the B.C.G. vaccination against tuberculosis in cattle and pleuropneumonia complement fixation, by Mr. T. S. Gregory ; and the investigations into worm nests, *Onchocerca gibsoni*, by Mr. G. MacLennan. Mr. H. E. Albiston explained the method adopted in examining the Melbourne milk supply for its bacterial content, and gave me some information about the prevalence of contagious mammitis, actinomycosis in cattle, and helminthic infection of sheep, in which subjects he had special experience. Subsequently a visit was made to Gippsland in the company of Mr. MacLennan, to examine some cattle which showed the presence of so-called worm nests, *Onchocerca gibsoni*, a condition that had apparently arisen in local cattle, whereas, so I was informed, these parasites are usually found only in cattle from Queensland and the northern parts of Australia.

An excursion was made through the country in which the infested cattle so far had been found. Whilst in Melbourne a visit was made to the Messrs. Angliss Co. Pty. Ltd.'s freezing works, in company with Mr. R. P. Allen, of the Department of Markets, and Colonel Dunlop Young, of the Smithfield Abattoir. A visit was also paid to the Municipal Abattoir. The method of meat inspection was looked into, and inquiries were made with regard to the prevalence of diseased conditions, particularly caseous lymphadenitis, onchocerciasis, and tuberculosis, as well as the presence of the parasites usually found, such as liver-fluke, lungworms, and other intestinal worms. Opportunity was given by the Superintendent, Mr. J. S. Penrose, for me to examine the entrails of a number of slaughtered sheep, and the absence of nematodes in the stomach and the intestines was noticed. I also called on Mr. A. E. Kendall, Chief Veterinary Officer of the Department of Agriculture, and information was obtained about the working of his department and the diseases he was dealing with. We discussed pleuro-pneumonia, contagious mammitis, actinomycosis, swine-fever, and swine plague, contagious abortion, sterility in cattle, parasitic infections, &c. Whilst in Melbourne I also took advantage of an opportunity to discuss with Dr. Bordeaux, D.V.Sc., the question of the so-called osteoporosis in horses, now known as osteofibrosis, a disease generally thought to be caused by wrong nutrition. He gave me a *résumé* of his observations, and showed me a horse still suffering from the disease. I also had the privilege of meeting Dr. J. A. Gilruth, formerly Director of the Melbourne University Veterinary School, whose wide experience in diseases of New Zealand and Australia, with particular reference to black disease and braxy-like disease, was of great interest to me. In the company of Dr. W. A. N. Robertson I paid a visit to the Commonwealth Serum Institute, where I met the Director, Dr. S. G. Morgan, who explained the activities of the Institute. I was received by Dr. Chas. Kellaway, Director of the Walter and Eliza Hall Institute of Research, and shown over the place. Dr. Hamilton Fairley demonstrated his investigations into the poisonous snakes of Australia. We also had a discussion about hydatid infection in men and animals. With Mr. Turner and Mr. Murnane a visit was made to Kerang, where investigations are being carried out into black disease. Opportunities for a post-mortem examination occurred and the disease was explained; also the possible connexion with liver-fluke as a primary condition. Information about the prevalence of liver-fluke, lungworms, enteric helminthic infections, lymphadenitis, blowfly ravages, and swelled head, was also obtained. Subsequently, a case of yellows was demonstrated in the Veterinary Institute on material collected by Mr. MacLennan. This disease was recognized by me to be identical with the enzootic icterus of sheep in South Africa. On this occasion, a visit was also paid to Dr. T. Cherry, of the Cancer Research Division, where I saw the results of his very fascinating investigations. On the 30th April, a visit was paid to Mr. Lionel Weatherly, B.A., at his station, Woolongoon, near Mortlake, where I obtained some information about the ravages of the blowfly and the occurrence of footrot. Opportunities were given to observe cases of caseous lymphadenitis and the absence of nematodic infection in some killers. The fertility of ewes and the cause of death of lambs also were discussed. Signs of deficiency could not be detected in this area, although it was stated by Mr. Weatherly that in dry years cows were noticed to chew bones. At the time, the pasture was in first-class condition owing to late summer rains. In company with Mr. Weatherly I went to the station, Blythsdale, where again an opportunity was given, by killing a few sheep, to look for the presence of intestinal worms. With the exception of a few hydatid cysts, none were found. In Blythsdale, experiments were pointed out to me, undertaken in conjunction with officers of the Department of Agriculture, to study the influence of top-dressed natural pasture on the carrying capacity for sheep and the influence on wool-production and quality. These experiments have only recently been commenced, and are intended to be carried out over a period of at least three years, with the object of studying the carrying capacity and the influence on the sheep and the wool. Mr. Weatherly also took me to a race meeting at Warrnambool, and introduced me to a number of pastoralists, with whom I had occasion to discuss their experience on deficiency in stock in general and the influence of top-dressing in their respective areas. The questions of blowfly, footrot, and parasites came also under review. After my return, I had a long interview with the Director of Agriculture, Dr. S. S. Cameron, about the problems of stock-breeding and deficiencies in Victoria. His experience with phosphorus deficiency as a limiting factor in horse-breeding and its presence in cattle previous to top-dressing of pasture is particularly valuable. Dr. Cameron also gave me an opportunity to go with the Better Farming Train, in charge of Mr. R. J. de C. Talbot, to Winchelsea, Western Victoria. Mr. R. N. Johnstone, of the Stock Department, accompanied me. The exhibits of the train were inspected. The demonstration of poisonous plants showed me the importance of this subject. Mr. W. D. Shew, Veterinary Officer of the train, made arrangements with a farmer, who complained about a disease in his sheep, to despatch a sheep to the Veterinary Institute. Two days later I had an opportunity to see the post-mortem, made by Mr. Albiston, and noticed the prevalence of stomach worms, an infection as bad as I had ever seen it in South Africa. On the Better Farming Train I also saw the exhibition of sheep by Mr. N. A. Bowman, Sheep and Wool Expert. I also attended a lecture of the expert in breeding of dairy cattle, Mr. J. M. Kerr, and so got to know the efforts of the Department of Agriculture to improve milk production. On the 4th May, I gave a lecture before the Royal Society and the Veterinary Association of Victoria on phosphorus deficiency in cattle. On the 11th of May, a visit was made with Dr. Cameron and his agricultural experts to the University School of Agriculture. The activities were explained to me by Professor S. M. Wadham. Problems connected with mineral deficiency in pasture and stock were passed under review as affecting Victoria. On the 10th May, a meeting with Dr. Orr took place, and notes were exchanged concerning his observations made during his trip. During my stay in Melbourne, I had several times the privilege of discussing with Mr. G. F. Hill, entomologist of the Council, various problems, such as blowfly, buffalo-fly, &c.

2. Visits in New South Wales.

On the 12th May I left Melbourne for the Riverina, and arrived the same evening at Deniliquin, where I was received by the manager of Barratta, Mr. Cameron, and taken to the station, where I stayed till the 14th May. Dr. Orr had also visited this station. This visit gave me an occasion to discuss the question of breeding and fertility in sheep. I had an opportunity to inspect the pasture and see the salt bush country, so characteristic of some parts of the Riverina, and which in some respects resembles the Karoo in South Africa.

I arrived in Sydney on the 15th May, and was met by Colonel Max Henry, Chief Veterinary Officer of the State Department of Agriculture. During the day Mr. Henry introduced me to Dr. H. R. Seddon and and Mr. C. L. O'Gorman. He explained to me the organization of his Department, his policy, and the problems he was dealing with. A visit was made the same day to the Quarantine Station with Mr. O'Gorman. The facilities for isolation and observation of imported animals were explained to me, also the treatment of dogs for intestinal parasites to exclude the importation of parasites not yet observed in Australia, and affecting domesticated animals for which the dog could act as an intermediary host. The 17th and 18th May were spent in Glenfield, at the Veterinary Research Station, the Director of which, Dr. Seddon, had very kindly prepared a memorandum for me, on all the activities of his laboratory and the problems existing in New South Wales. I had a good opportunity to discuss the various subjects under investigation by him and the staff under his direction. The problems brought to my notice were : Intestinal worm infection in sheep (liver-fluke, stomach worms), poisonous plants (staggers in sheep, stringhalt in horses), the influence on animals of photo-sensitizing and cyanogenetic principles in plants, the effect of carbon tetrachloride on cattle suffering from mineral deficiencies, contagious abortion, arthritis in lambs and pigs, caseous lymphadenitis in sheep, yellows in sheep, scabby mouth in lambs, swelled head in rams, the presence of pathogenetic anaerobes in different soils (the causes of such diseases as tetanus, malignant oedema, botulism, and black-quarter), effects of dips and sprays on cattle exposed to various climatic conditions and dips affecting lice and ticks in sheep, the blow-fly problem from the point of view of prevention and cure by spraying and jetting, and also the study of conditions leading to blow-fly infestation. Investigations in myxoma in rabbits, plethoric toxaemia, and the so-called pulpy kidney in lambs, were also discussed. Mr. W. A. Carr Fraser, an officer of the Council, explained the result of his investigations into the paralysis of pigs, and demonstrated the effect of deficient nutrition in pigs. A collection of valuable material for pathological investigation has been made at Glenfield.

On the 21st May Dr. Orr returned to Sydney before his departure for England. With him, I met Mr. G. A. Julius to discuss research problems connected with nutrition, the aspect of mineral deficiencies in which both of us are interested. On the 22nd May, in the company of Mr. O'Gorman, I paid a visit to the Hawkesbury Agricultural College and was well received by the Principal, Mr. A. E. Southee. I discussed with the Veterinary Officer, Mr. Whitehouse, the position of worm infection in sheep, in which problem he has had considerable experience. Whilst in Sydney a meeting with the State Committee of the Council, with Professor R. D. Watt in the chair, was held, and a short address given expounding the line of research work in animal health in which I had been engaged during my stay in South Africa. The Under-Secretary for Agriculture, Mr. G. D. Ross, also gave me an opportunity of discussing certain pastoral problems. He introduced me to Mr. J. N. Whittet, Agrostologist to the Department, who showed me at the Botanical Gardens the different grasses of interest to New South Wales. During my stay in Sydney, several visits were paid to the Veterinary School at the University, and the question of veterinary training with special reference to the problems of Australia, and in particular the training for research work, was discussed with Professor J. Douglas Stewart. His wide experience with animal diseases was very useful to me. Opportunity was also taken to discuss with Dr. I. Clunies Ross the problems of intestinal parasites, especially in sheep, and their distribution in Australia as far as this was known. Information was also obtained concerning his research work about liver-fluke. With Mr. H. R. Carne I discussed the problems of contagious mammitis, and he gave me an opportunity to read his manuscript of a proposed publication on his inquiries and researches into this question, which he carried out whilst in Paris. The question of caseous lymphadenitis came also under review. Mr. R. M. C. Gunn explained to me his research into rickets as a result of deficient nutrition and his proposed work into the so-called stringhalt of Australian horses, with special reference to the functions of the sympathetic system.

On the 25th May I left for Lismore in company with Dr. W. A. N. Robertson and Colonel Max Henry. The object of the visit was to obtain information about the working of the system in vogue for eradication of tick in that district and for prevention of its spread further south. The officer-in-charge of the work, Major C. J. Sanderson, was met in Lismore. There was a meeting with the local board attending to this work. A visit was also paid to the Dip Testing Station at Lismore, in charge of Mr. L. Cohen. On the 29th a meeting was held with the Board in Murwillumbah. The members of the Board were particularly interested in the tick problem as it occurs in South Africa, and the position was explained to them. On the 30th May the party left for Brisbane on a very short preliminary visit, and on the 31st a meeting was held of the Cattle Tick Dips Committee of the Council. The discussion related mainly to a comparison of the methods for the eradication of tick as employed in South Africa and in Australia, with special reference to the interval in dipping, the strength of the dip, and the possible leakages in the different methods. In the company of the Committee, a visit was paid to an experimental field near Brisbane, where dipping of cattle is carried out, and results were inspected and discussed. The return journey to Sydney was made on the 2nd and 3rd June.

On the 6th June I went to Orange, where I was received by the District Veterinary Officer, Mr. Belschner. He explained to me the working of his office and the problems with which he was confronted.

I was met at Orange by Mr. J. N. Whittet, Agrostologist of the Department of Agriculture, who showed me the effect of top-dressing, the growing of clovers, and the improvement of pastures generally on the farms Willawang and Tantallon. In company with Mr. Belschner, we boarded the train in Wellington on the morning of the 8th, and met Dr. Seddon, who was to accompany us to Warren and Nyngan. We visited the stations Raby and Canonbar, near Warren, on the 8th, 9th, and 10th June. This visit offered opportunity to obtain information about the ravages of blow-fly, swelled head in rams, the presence of parasitic intestinal infestation, the observation of sterility in rams, and the influence of climate and pasture on the breeding of sheep and wool. On the 11th June, we went to Nyngan, to see the experimental station for the purpose of studying the blowfly pest, in charge of an officer of the Council, Mr. C. R. Mulhearn, and under the direction of Dr. Seddon. The object of the experiments was to study the conditions which led to any particular sheep being blown, and careful statistics were kept for this purpose. The effect of jetting and spraying is also under investigation here. There were also some feeding experiments carried out on sheep, and the effect on wool was studied. On the return journey I was met by Colonel Max Henry in Dubbo on the 11th, and Dr. Seddon returned to his head-quarters, Mr. Belschner brought us to Dunedoo, where a car sent by Mr. Fred. MacMaster picked us up and brought us to Dalkeith, near Cassilis. We stayed in Dalkeith until the 14th, when we left for Mudgee to pick up the train for Sydney. The stay in Dalkeith gave me an opportunity to discuss with Mr. MacMaster the breeding of merino sheep and the practice observed by him ; the questions of feeding licks and nutrition in general were put under review and useful observations obtained about the prevalence of blowflies and their ravages. The pest had been particularly bad in this place. Observations were also made about some skin troubles as affecting one or two sheep, and information obtained about the occurrence of footrot under certain conditions. Rainy weather unfortunately prevented us from examining Mr. MacMaster's flocks, but the opportunity to inspect his rams was not missed.

On the 15th June I addressed, in Sydney, the National Council of Woolselling Brokers of Australia and the Australian Woolgrowers Council, at a meeting presided over by Mr. G. L. Aitken, Chairman of the National Council of Woolselling Brokers. The address was well received and led to some discussion. It was subsequently printed. In that address I gave some information which I had gathered up to that time on pastoral problems connected with animal health.

On the 17th June I left, in company with Dr. Seddon, for Bobundara, in the tablelands of Monaro, to obtain first-hand information about the prevalence of liver-fluke, the occurrence of black disease, and the distribution of snails. We had opportunities to make two post-mortem examinations of sheep which had succumbed to black disease. Mr. Mawson, manager of the station, explained to me the methods adopted and the results so far obtained by the application of bluestone in the habitats of the snails, and the effect of drenching the sheep with carbon tetrachloride. Opportunity was also given to examine two killers for the presence of intestinal worms, which, however, were absent in this case. On the return to Sydney a stay was made in Cooma, where a meeting of pastoralists was addressed by myself and Dr. Seddon. The main questions were about liver-fluke and black disease.

On the 21st June a visit was made to Camden Park in company with Colonel Max Henry. General Onslow was very kind in showing us the historic flock which is the progeny of the famous Macarthur flock. It occurred to me that here there was preserved very useful material for research in sheep genetics of which full advantage should be taken. Such material, with a definite history, should prove most useful for this purpose.

Whilst in Sydney, I also paid a visit to the Metropolitan Abattoirs under the directorship of Mr. J. B. Cramsie, who, with his veterinary inspectors, Mr. Thorpe and Mr. Drabble, kindly conducted me through the institution. There is attached to the place a laboratory for diagnostic work. I have realized the great opportunities which such an institution offers for pathological research in animal diseases in all classes of stock, the occurrence of lymphadenitis in particular, and that of parasites and their geographical distribution, thus serving as an index to their prevalence under definite climatic and telluric conditions, provided the origin of the animals could be obtained; which information, however, I was told it would be difficult to collect.

Whilst in Sydney I gave to the New South Wales Veterinary Associations and their guests a lecture on the animal diseases of Africa, a subject that possessed much interest for the audience. The discussion gave me some useful information about the presence of parasitic diseases, particularly about oesophagostomiasis.

3. Visits in Queensland.

On the 23rd June I left for Brisbane. I arrived there on the following day and was met by Professor H. C. Richards, Chairman of the State Committee of the Council, and Mr. A. H. Cory, Chief Stock Inspector. I called on Mr. W. L. Payne, of the Lands Department, who explained to me the policy of the Department with reference to pastoral settlements. A discussion with Mr. E. Graham, the Under-Secretary for Agriculture, gave me information concerning the problems in which he was interested. I had also the pleasure of meeting the Premier, the Hon. Mr. W. McCormack, and the Minister for Agriculture, the Hon. Mr. E. Forgan Smith.

Both gentlemen showed great interest in my visit to Queensland. During the stay in Brisbane, an address was delivered to a meeting of the Graziers' Association, with his Excellency the Governor in the chair. The meeting was called by Mr. A. E. Coldham, executive officer of the Association. Subsequently I went to the Stock Laboratory at Yeerongpilly, under Mr. C. J. Pound. Information was looked for and obtained concerning the method of immunization against redwater in cattle. The visit was in company with Mr. Cory, and I learned from both these gentlemen that the drug trypanblue, of which much use was made in South Africa and elsewhere with excellent results in the treatment of redwater, had been found to fail in Queensland. This was rather a surprise to me, as in South Africa we could rely on the efficacy of this drug. I am under the impression that the material used in Queensland was not the same as that used in South Africa. Information was also obtained concerning the reaction in animals undergoing immunization and the resulting immunity. Subsequently, a visit to the freezing works was made and some information collected about the supply and quality of slaughter stock.

On the 27th, I left for Rockhampton and arrived there on the following day, meeting there Mr. C. L. Macdonald and Mr. E. W. Archer. A meeting with pastoralists had been arranged, and an address was given to explain the object of the visit. I had the opportunity of meeting several pastoralists in private conversation and obtained their experience in connexion with pleuro-pneumonia, redwater, and tick infestation, the main troubles which occupied their minds. On the occasion of a visit to the butter factory in Rockhampton, in company with Mr. T. L. Wilson, I heard of the necessity of obtaining more knowledge concerning the manufacture of butter under the semi-tropical conditions of this part of Queensland.

On 29th September, I left for Longreach. On the train I had the company of two graziers I had met in Rockhampton, and information about poisonous plants, particularly heart-leaf (*Gastrolobium*), and the toxic effects of a plant known as fuchsia, was given to me. I arrived in Longreach on the 30th, being met there by Mr. E. H. Phillips, secretary of Central and Northern Queensland Graziers' Association. A meeting with graziers was held that evening and I explained the object of the visit. This portion of Queensland was at that time suffering from a drought that had not broken for the last four years. I found it somewhat difficult to speak about research in problems of animal health, when there were practically no animals alive, and of those that were, many were in a starving condition. I was informed that otherwise the district was a healthy one and no diseases were known. I could understand this to a certain extent. One speaker stated that the main troubles they suffered from were taxes, the dingo, and the burr. If these could be removed the country would benefit. There was also some discussion about blowflies. I was under the impression that under the influence of the droughts, the pastoralists had forgotten all other troubles associated with stock.

On 1st July, Mr. Phillips drove us to Darr River Downs Station, where I met the manager, Mr. H. E. G. Whitla. This station had apparently not been so severely hit by the drought; there was still Mitchell grass pasture in fair condition in which fat sheep were running. Mr. Whitla showed me one of the artesian wells which supplied the drinking water for the stock. It was mineralized water, but apparently the stock did well on it. At Darr River Downs I met a number of pastoralists, and the topic of interest was deficiency. I was informed that at one time of the year, even in a good year, the pasture was apparently lacking in some substance, since stock, particularly sheep, at that time lost condition

I was asked whether such a deficiency might be removed by the supply of licks, and, if so, by what kind of licks. In the absence of more information, I was unable to form an opinion, but seeing that the area was one of extreme arid condition it is likely that the deficiency is not alone one of minerals but also of proteins, or generally a defective nutrition.

On Monday, 2nd July, I was driven by Mr. Whitla to Moscow Station, and received by Mr. Fergus McMaster. Conditions similar to or even worse than those at Longreach were noticed. Mr. McMaster is making an attempt to grow some fodder trees on his property and thinks that experiments in this direction should be made. Mr. McMaster drove me to Winton, where I addressed a graziers' meeting in the afternoon, he being in the chair. There was the same difficulty. Drought and starvation were everywhere, and the question of maintaining health was less important than that of life, even if only poor-conditioned animals were possible. However, here also the problem of deficiency apart from starvation was suggested as one of interest for research. The main discussion was about the cultivation of pasture under arid conditions, also preservation and transport of fodder. The problem apparently resolved itself into one mainly affecting the agrostologist and the botanist. The blowfly was also discussed. Some minor troubles such as hydatids in sheep were mentioned. The question of fecundity in sheep was brought up, and I learned that a marking of only 35 per cent. of lambs was frequently observed, particularly under droughty conditions. This, of course, meant the survival of lambs at that time and gave no definite clue as to the actual number of births. I left Winton the same evening for Manuka in company of Mr. Baxter. There was again the problem of drought. Mr. Baxter was feeding his sheep and had composed a fairly balanced ration to which he had added Nauru phosphate to meet the phosphorus deficiency. The Manuka sheep were certainly not fat, but had by no means a starved appearance. Mr. Baxter also emphasized the necessity of more knowledge concerning deficiency apart from that of provision of food in seasons of drought. I observed on this farm the first case of so-called cancer, to which my attention had not been drawn hitherto. The problems of poisonous plants were also discussed, Mr. Baxter being able to give me some observations he had noticed with hungry sheep that were detrained and died of the effects of feeding in a certain pasture. I left Manuka in the morning with Mr. Brodie, the manager for Dr. H. Carlyle Taylor, of Katandra, where I arrived at noon and left again early in the afternoon for Hughenden, where I was received by Mr. Geary, the President of the Graziers' Association. All the way we passed through drought-stricken country. Mr. Brodie pointed out to me *en route* the various trees that were used as fodder plants for sheep as a so-called stand by. A tree locally known as whitewood was pointed out to me as being the cause of a disease in horses, called staggers or walkabout.

At the meeting in Hughenden, I was again confronted with the fact that it was an area of starving conditions for stock. There were accordingly no problems of health. Rain was the great deficiency of the moment. However, I realized that also here pastoralists had the opinion that the pasture was, even when plentiful at certain times of the year, lacking in nutritional value, which was thought to be due to deficiency of some kind. There were practically no diseases in this part of the country, and I admitted that at least as far as parasitic infections were concerned there was not sufficient moisture for worms to keep alive. It was admitted by some speakers that swelled head in rams was occasionally seen, and that fatalities due to plant poisoning had occurred. One speaker was out for information concerning the so-called cancer in sheep. The question of fecundity in ewes was also touched upon, but it was difficult to obtain accurate information. The percentage of lambs is calculated at the time of marking; it is accordingly not possible to tell exactly how much of the shortage is due to sterility of ewes and how much to mortality of lambs. I left Hughenden in the morning of 5th July for Charters Towers, and was met there by Mr. E. D. White and a party of graziers. A meeting was held the same evening and the discussion was exclusively about cattle tick, redwater, pleuro-pneumonia, plant poisoning and speargrass. There were also indications of mineral deficiencies, and the presence of some unknown disease in cattle was mentioned, which appeared to me to be botulism. The discussion in the meeting itself was, however, not particularly informative. I obtained the main information in private discussion with the various pastoralists. Attention was drawn to damage due to tick worry. There was a discussion on the possibility of breeding tick-proof or tick-tolerant cattle by crossing with Indian cattle or by selection. I was pleased that with Charters Towers the formal meetings came to an end. From my point of view they were not always very satisfactory; the main reason apparently was the drought-stricken condition of the areas visited, which dominated all other problems, and a general reluctance on the part of the farmers to give information in open meetings which, however, was readily obtainable in private conversation. Moreover, the farmers were out for information, which I was unable to give, or unwilling to give, since it was not one of my functions. In Hughenden, some disappointment was expressed by one speaker about this. People came from long distances to hear what I had to say, and expected to leave with information which, as a matter of fact, they could not obtain from me.

On the morning of 3rd July, I left for Townsville and was met by two officers of the Stock Department. With them I went to the Stock Experiment Station. The officer-in-charge, Dr. John Legg, was at the time absent in the Gulf country investigating the spread of the buffalo-fly, which was reported to have reached the Queensland border. At the station the chemical assistant was able to give me some information concerning the experiments carried out with dippings at different intervals. Since then I have been able to read a report provisionally submitted by Dr. Legg, which contains valuable data on the subject. I should like to see this report brought to a conclusion and published. A visit to the Townsville Institute for Tropical Medicine was made, and I discussed with Dr. G. H. Heydon the question of onchocerciasis in cattle, he having been able to show the presence of larvae in rather great numbers in the skin of cattle, a suggestive observation indicating how the infection may be obtained by bloodsucking vectors. Information was also collected from the stock inspectors concerning the prevalence of disease in stock, particularly parasitic infestations, caseous lymphadenitis in sheep, the effects of speargrass in sheep, tuberculosis, contagious abortion, onchocerciasis, &c. The freezing works were also visited.

I left Townsville for Cairns on 6th July. I received a visit from the local abattoir inspector, and he gave me information about the pathological conditions met in this part of the country, viz., onchocerciasis, lymphadenitis, parasitic infection, &c. He had seen lumpy guts in sheep at times (*Oesophagostomum columbianum*).

On 7th July I travelled to the Atherton Tablelands. The dairy inspector at Yungaburra, Mr. Hagen, took me to a rather well-developed dairy farm belonging to Mr. Roseblade. There were no complaints about health conditions of cattle in this part of the country. However, the proprietor of the farm thought there was some deficiency in his pasture which he was not able to explain, and which did not yield to top-dressing. Subsequently, I learned that attempts to grow sheep on the tablelands had to be abandoned mainly on account of worm infestation, particularly the one responsible for lumpy guts (*Oesophagostomum columbianum*).

On the 10th, I returned to Cairns via Kuranda and was met by the Senior Stock Inspector *en route*. I was able to obtain some information based on his experiments with pleuro-pneumonia and redwater in cattle. In Cairns on the 10th I was introduced to a grazier from the Gulf country. He was mainly interested in pleuro-pneumonia, tick worry, redwater and immunization for redwater. Incidentally, he mentioned the difficulty of rearing foals supposed to be suffering from rickets. I was unable to identify this disease with true rickets ; its nature remained obscure.

On the 11th I left for Brisbane. I had a stay of three hours in Townsville, and Dr. Legg, who had meanwhile returned from his mission in the Gulf country, met me at the station. This short meeting allowed me to interrogate him on some of the problems on which he was working—the immunization of cattle against redwater, the immunity obtained by this process, the failure of the drug trypanblue, and the presence or absence of certain blood parasites other than *Piroplasma bigeminum* in tick cattle.

Leaving Townsville the same evening, I arrived in Brisbane on 13th July. In the afternoon of the same day I attended a meeting of the Faculty of Agriculture at the University and gave some of the impressions I had gathered on my visit to the north. On 15th July, I went to the Gatton Agricultural College, and with Principal J. K. Murray I inspected the cattle and pigs and drove over the fields. A short address had to be given to the students at luncheon time. I stayed in Brisbane on the 14th, 15th, 16th, 17th, and 18th July, and during this time I took the opportunity to discuss some of my observations with Mr. Cory, Mr. Pound, Mr. Brown, late sheep inspector, and with Mr. J. C. Brunnich, the Chief Chemist of the Department of Agriculture. It was particularly from the latter that I received interesting and useful information about phosphorus deficiency in Queensland and the effect of Nauru or rock phosphate as an ingredient of stock licks; the question of mineralized drinking water was also touched upon. Mr. Brown was able to give me information about the prevalence of certain intestinal parasites, particularly the nodular worm (*Oesophagostomum columbianum*), which I had not seen yet in any of the stations I had visited. I am also indebted to him for much information about the effects of licks containing Nauru phosphate for sheep. I paid another visit to Yeerongpilly, in order to examine some blood smears of bleeders that Mr. Pound had promised to collect for my examination after return from the north, and I was able to convince myself of the presence of another parasite originally described by myself in South Africa as *Piroplasma mutans* and now referred to generally as *Theileria mutans*. This parasite is of little economic consequence, but to me it was an indication that the temperature reactions of cattle undergoing immunization against redwater were due to different incubation periods of two parasites.

Mr. C. T. White, the Government Botanist, obliged me with information about the poisonous plants of Queensland and the botanical names of fodder trees, which I had seen during my travels.

Professor E. J. Goddard was very kind in showing me bunchy top in bananas, a disease due to an ultravisible organism, in which I am particularly interested, and the work done at Sherwood in connexion with the biological control of the prickly pear. During my stay in Brisbane I delivered a lecture to the Royal Society of Queensland on phosphorus deficiency in animals, a topic of considerable interest to Queensland.

On Tuesday, 17th July, I attended a meeting of the State Committee of the Council, to which several officers of the Department of Agriculture had been invited as well. I gave a short *résumé* of my observations and impressions to the effect that the outstanding problem of the areas visited was the drought problem and that research in the direction of growing foodstuffs suitable in these areas was indicated; that the question of deficiency was certainly one that deserved attention, and since it applied to conditions in tropical regions with a small rainfall, it was one that was of importance to other parts of the British Empire, e.g., in Africa and Asia, with similar problems; that the question of further research into the causative agencies of redwater and allied diseases was indicated; that the use of the drug trypanblue in the process of immunization and as a curative treatment should be studied; that the question of immunity in redwater should be re-opened; and that the investigations into tick-destroying agencies should not be relaxed, in order to destroy the last elusive tick. I felt that there were yet other problems peculiar to Queensland that would be found on closer examination, particularly in connexion with poisonous plants. I came to the conclusion that further research work in Queensland would be justified. I also made the statement at the meeting that I found the pastoralists generally anxious to have information concerning nutritional problems. It appeared to me that well-organized propaganda and demonstration work of what was known and how that knowledge could be applied was indicated as a necessity in Queensland.

On 20th July, I left for Jondaryan Station and was received by Mr. Wm. Kent. This was one of the places that had previously been visited by Dr. Orr. Mr. Kent only had wethers, which he bought as four-tooth animals and sold after two or three shearings. He explained to me that it was difficult, or at least unprofitable, to rear sheep on his station, whereas he experienced practically no difficulty with wethers. He was not able to understand this, and thought that some deficiency might be responsible. He informed me also that he had a certain amount of stomach-worm infestation at present, particularly in two-tooth sheep, which he had recently bought contrary to his usual practice. However, this worm trouble, he thought, was of minor importance, since he was able to combat it successfully by dosing. The two-tooth animals on this occasion did not, however, seem to respond to the treatment, and he was repeating the dosing the day after my arrival. The following day this operation was carried out in my presence, and Mr. Kent then picked out two sheep that appeared to be worm-infested and an autopsy was made. It demonstrated the efficacy of dosing as far as stomach worms were concerned. None were found, but the presence, in unusual numbers, of *Oesophagostomum columbianum*, the nodular worm, and the cause of lumpy guts, was noted. There is no effective drug treatment against this parasite. Its presence explained to me at once the difficulty of rearing lambs, since it is mainly a parasite of young sheep, against which older sheep acquire a great amount of resistance. Sheep at different ages and from various paddocks were examined. The parasites were not found in all sheep. Mr. Kent was under the impression that sheep in a paddock supplied by a fairly charged mineral water suffered less than others, an observation that may be of some importance but may be a mere coincidence. The ravages of blowfly and the presence of lymphadenitis and hydatids came under discussion and demonstration. I had also an opportunity to see a case of so-called staggers in a wether, suggesting that possibly toxic plants may be responsible. Mr. Kent's station has both summer and winter rains, and this, in my opinion, explains to some extent the prevalence of the nodular worm, which I had not seen as yet in purely winter rainfall countries. I also had occasion to see the so-called balanitis, or pizzle, as a serious trouble in wethers. There is a rough-and-ready way of treating this trouble, but such wethers have a decreased market value.

I left on the 23rd for Toowoomba, and by train for Stanthorpe, where I was received by Mr. Rogers and taken to the station Pikedale. The following day was, unfortunately, rainy, and consequently it was impossible to go out into the paddocks. A number of neighbouring pastoralists had assembled on this day, and a most profitable discussion resulted on practically all the topics of animal health as it affected sheep in this part of the country. Mr. Rogers submitted for post-mortem examination a lamb that he thought was worm-infested, although he had dosed it some days previously. It did not respond to treatment. This was his experience for the current year, whilst in former years he had always noted improvement after dosing. The post-mortem examination revealed the presence of *Oesophagostomum columbianum*, also in great numbers, and the cause of the non-response to treatment was clear. This portion of Queensland also has summer and winter rains. The pastoralists were all interested in the question of deficiency. I somehow formed the impression that pastoralists are inclined to ascribe many of their troubles to nutritional defects, but certainly the lumpy guts of the Darling Downs, or anywhere else, cannot be put down to this.

On the return journey to Brisbane on 26th July, I met Sir John Russell in the train and we travelled together to Sydney, comparing notes on the way down. With Sir John I attended a meeting of the Executive Committee of the Council. The same evening I left for Canberra in company with Mr. Julius, Professor Richardson, and Dr. Rivett. Here the site reserved for the building of the scientific head-quarters of the Council was shown to me. I was impressed by the suitability of the site for this purpose. I gathered that there would be no difficulty in also finding a suitable place for buildings for a laboratory for animal research should it be thought advisable to build such in Canberra. This question requires careful consideration, since a number of factors, such as proximity of infectious diseases, disposal of carcasses, &c., that do not enter in the case of other scientific research institutes, come into consideration.

4. Visits in Tasmania.

On the 28th, I arrived in Melbourne and arrangements were immediately made for the trip to Tasmania. This journey was started on the 1st of August and I arrived in Launceston the following day. I was met by Mr. P. E. Keam, the chairman of the State Committee of the Council, by Mr. T. Philp, Senior Veterinary Officer of the Department of Agriculture, and by Mr. D. T. Oxer, Veterinary Research Officer. The same afternoon, in company with Mr. Keam and Mr. Philp, I left for Scotsdale. We spent an evening at the house of Mr. Salier, where a number of pastoralists interested in stock problems assembled. The question of deficiency was discussed, but my attention was particularly drawn to the prevalence of a disease in sheep that for lack of a better name is called "twin disease," ewes pregnant with twins mainly succumbing to it. The conditions under which this disease was noted to occur were explained. The following day the party proceeded to Winnaleah, Herrick, and Gladstone. The discussions were mainly concerning deficiency, of which farmers had evidently much experience. Cattle so affected were called "coasty." They recovered when brought to the richer inland soils. In Gladstone, I had the opportunity of seeing a typical case in a cow. It was identical with the South African stiffsickness. The night of the 4th of July was spent in St. Helens, and the following day the party proceeded to Fingal, inspecting cattle, sheep and pasture *en route.* Evidence of phosphorus deficiency was obvious in many places and was often very marked. The afternoon of the 5th July was spent at Fordsleigh with Mr. Brodribb. This gentleman had been in communication with me some years ago concerning parasitic infection of sheep on his farm, had sought from me information about the method recommended in South Africa for the treatment of this trouble, and was able to show me that he had applied it with complete success to his flock. I understand a report about this has been supplied some time ago for the information of the

Council. I also had, on this place, an excellent opportunity of seeing a calf recently brought from the coast suffering from extreme effects of phosphorus deficiency and liver-fluke infestation.

The night of the 5th was spent in Fingal, where I had the pleasure of meeting Mr. F. E. Ward, Director of Agriculture, who had come to meet me. He drove me the following day to Mr. G. F. Mackinnon's station, Vaucluse, and here again an opportunity was afforded for the inspection of some cattle that showed signs of phosphorus deficiency. The question of botulism in cattle, known in this part of the country as Midland cattle disease, came under review, as did the effect of licks as preventive measures. In the afternoon we arrived in Campbelltown. A visit was paid to Mr. Clarke, a famous game hunter of Africa. He being interested in sheep, information was sought and obtained about the so-called twin disease and parasitic infection. Lungworms were mentioned as of some consequence. The night was spent at Merton Vale as the guest of Mr. Foster, jun. He showed me his sheep running near the homestead. They were running on cultivated pasture lands, but I realized from the appearance of the cattle I noticed on the way that the natural pasture must be phosphorus deficient. On 7th August we went to Streanghal, Mr. Nicholson's station. It was on this place some years ago that Mr. Philp carried out experiments which showed that the deficiency observed in cattle in this district could be prevented and cured by licks containing bonemeal. The remnants of the experimental paddocks, watering arrangements, and crushes were still to be seen. An examination of the cattle running in this pasture was made, and they showed pronounced signs of phosphorus deficiency. Mr. Nicholson informed me that he did not keep cattle as a paying proposition, but used them to eat out the rank grass of the natural pasture to render it fit for his sheep. He showed us one of his rams, an excellent Corriedale, that he kept stalled and well fed. We visited the adjoining station (Winton) of Mr. Taylor, and there saw some excellent rams running on top-dressed pasture lands. Mr. Taylor also showed me the very fine wool produced on his run. The same afternoon I gave a lantern-slide lecture to a meeting of pastoralists and farmers in Campbelltown. It was well attended, and led to some discussion concerning deficiency and botulism. The so-called twin disease in sheep was also mentioned, and also parasitic infections observed in Tasmania, flukes, stomach worms and lungworms. On the morning of the 8th, the party, consisting now of Mr. Keam, Mr. Ward, Mr. Philp, and Mr. Oxer, proceeded to Hobart taking notice of cattle, sheep and pasture *en route*.

On the 9th, I visited the abattoirs in Hobart, being received there by the mayor and his councillors. An examination of a number of sheep was made as to the presence of parasitic infection, and information obtained about the presence of tuberculosis, caseous lymphadenitis, &c. In the afternoon, a visit was paid to Colonel Blacklow, in Sorell, as a suitable place for information about the so-called twin disease. *En route* we observed some cattle vigorously chewing bones, indicating the phosphorus deficiency of the area. Colonel Blacklow was able to give me his experience about losses which occurred in sheep running on cultivated pasture, but no cases could be seen and no definite opinion formed.

It would appear that, besides twin disease, there are other troubles in sheep connected with intensive feeding on cultivated lands. In the evening I had a discussion with two pastoralists, and obtained information concerning the prevalence of liver-fluke and parasitic infection of sheep's intestines that were not known to me and of doubtful nature.

On the 10th we left Hobart and by motor drove to Springbanks, near Launceston, and spent the night as the guests of Mr. G. V. Gibson. Some pastoral colleagues of my host arrived that evening, and we had a comprehensive discussion on the problems that confronted these gentlemen, twin disease and parasitic infection being particularly under review. The following morning we visited a neighbouring station, and here I had the opportunity of observing a case of the so-called twin disease alive and a post-mortem was made subsequently. The lesions described to me previously, viz., fatty degeneration of the liver and waste of the muscular tissue, were markedly pronounced. The examination of the skeleton also revealed the existence of a marked phosphorus deficiency. The afternoon was spent at Mr. Youl's station, and here another opportunity occurred to make a post-mortem. This time the case was one of obstruction of the gullet caused by an extreme tumorlike swelling of the mediastinal glands due to caseous lymphadenitis. It was evident that mortality occurred in this area from more than one disease. Attention was also given to the presence of stomach worms that were found in this carcass, but they were only in moderate numbers. The specimens were identified as belonging to the genus *Ostertagia*. We returned the same afternoon to Launceston, very inclement weather making it impossible to visit other stations. On the 13th, I went to the Launceston abattoirs, and some sheep viscera were examined for parasitic infection. Information was collected about the prevalence of pathological conditions in slaughter stock, including tuberculosis, hydatids, flukes, lungworms, &c. A visit was also made to Mr. Philp's office, and pathological specimens collected by him were examined and discussed. From the conversation with Mr. Philp, I learned that in Tasmania there existed some diseases in horses, one known as the Waratah disease, resembling the Kimberley walkabout disease, showing characteristic lesions of cirrhosis of the liver, and another one, an ulcerative enteritis, suggestive of a parasitic infection. He also described to me the presence of a disease in King Island suggestive of iron deficiency as described in New Zealand, and of a most obscure disease in cattle ending with sudden death. Since then, Mr. Haynes, a manager of one of the estates in King Island, has given me some more information about its occurrence.

5. Visits in South Australia.

I returned to Melbourne on the 13th, and left for Adelaide on the 16th, being met at the station by the Chairman of the State Committee, Professor T. Brailsford Robertson, the Secretary, Mr. E. V. Clark, Mr. C. A. Loxton, Chief Inspector of Stock, and Dr. L. Bull. The rest of the morning was devoted to the Chief Inspector of Stock, who explained to me the scope of his activities and gave me a *résumé* of his experience. A visit was made subsequently to the pathological laboratory at the

Adelaide Hospital, under the direction of Dr. Bull. He introduced me to Mr. G. C. Dickinson, the Council's officer in charge of the Mount Gambier redwater investigations. Dr. Bull also explained the problems he had been, and is still, working on. The discussion was about the redwater disease, caseous lymphadenitis, swelled head in lambs, and parasitic infections.

I also had the pleasure of meeting the Hon. the Minister for Agriculture and Professor A. J. Perkins, Director of the local Department of Agriculture. The afternoon was spent at the Waite Institute, where Professor Richardson and his staff explained the various experiments in progress. I was particularly interested in the experiments undertaken to study the effect of top-dressing on the carrying capacity of pasture and the influence on the growth of the sheep and the wool.

On the 20th August, with Dr. Bull, I visited the Roseworthy Agricultural College. The Principal, Mr. W. R. Birkes, showed me the field experiments, and an inspection was made of the sheep-crossing experiments to establish the most suitable lamb for fattening and marketing purposes.

On the 21st, in company with Mr. Loxton and Mr. Dickinson, I left for Mount Gambier, where the latter gentleman had previously spent some time in collecting records about the distribution and prevalence of redwater disease. We visited three different farms where the disease existed, and on one of them we actually saw a case. The proprietor was willing to have the animal killed, and on the following day the post-mortem was made and the lesions as described to me beforehand were found. Whilst examining the cattle on this and other farms, we noticed that some of the cows were bone-chewing, and accordingly there could be no doubt about a phosphorus deficiency being present. Previous to the visit, Professor J. A. Prescott, of the Waite Institute, had pointed out to me that the same area was one in which manganese deficiency had been demonstrated, and that the distribution of the redwater disease and the manganese deficiency, which is principally shown in the growth of oats, were more or less the same. This is certainly a remarkable coincidence and deserves the closest attention.

On the 24th, the party left for the experimental farm at Kybybolite in charge of Mr. Cook, who demonstrated to us the effect of top-dressing of natural pasture. The striking results and contrasts obtained were convincing that we were in an area much deficient in phosphates. We also inspected the sheep and cattle. We arrived in Adelaide on the 25th. On Monday, the 27th August, in company with Mr. Loxton, I left for Koonoona, and spent the evening as the guest of Mr. W. G. Hawkes. On the following day the stud rams and a flock of ewes were inspected. Mr. Hawkes then brought us to Mr. Collins at Birra. We drove to Alberton Park to inspect the latter's rams. We passed through Mr. Eric Murray's station at Petherton, Mt. Bryan, and were handed over the same day to Mr. Stanley Hawker, who brought us in the evening to the station of his father, Mr. E. W. Hawker, in East Bungaree. This visit gave me an opportunity to see for myself the conditions under which the famous big-framed and strong-woolled South Australian sheep are grown.

A portion of the country was well cultivated, and extensive lucerne fields were in some parts very conspicuous. There were practically no complaints about the health of the sheep. It would appear, however, that sheep depastured in lucerne fields sometimes succumb to an acute disease, but only a limited number are attacked. We had the opportunity of seeing one such post-mortem, and the impression was obtained that the trouble was one of gastro-enteral location and possibly caused by a poisonous plant. There were no parasites found in this sheep, nor in a second one which was killed, and which was found to be in a wasted condition due to the presence of a chronic purulent pneumonia diagnosed at the post-mortem. The stud and the flock at East Bungaree were examined the next day, as well as the pasture. Mr. Stanley Hawker thought that some of his lambs were possibly suffering from worm infection, but a clinical examination did not reveal any anaemic conditions. Tapeworms could most likely be expected in lambs of that age. Mr. Stanley Hawker did not appear to be an enthusiast for top-dressing of natural pasture, and thought that the response to superphosphate hardly justified the expense. Indeed, he showed us a top-dressed natural pasture that could not be distinguished from the non-top-dressed one. This observation I thought was rather remarkable in view of the striking results seen in Kybybolite. What struck me forcibly in this area was the widespread distribution of the Cape tulip, a stock poison, that thrives remarkably well in this, its new home. During the day we drove to North Bungaree, a station belonging to Mr. M. S. Hawker, and the manager, Mr. Chomley, showed us the rams and one of the flocks of the well-bred strong South Australian merinos. We also inspected the pasture. There were practically no complaints about the health of the animals.

In the course of discussion with different gentlemen, I learned that many of the rams bred by them were sent to Western Australia, and that in that country a gradual change in the quality of the wool would take place, sometimes even so marked that in one and the same fibre two different characters could be recognized, which condition was explained to be a result of the difference in environment. I was informed that in Western Australian sheep it was frequently noted that the wool became too fine, which fact necessitated the constant introduction of strong woolled sheep into that State. On Mr. Eric Murray's station I saw some yearling rams of the famous Murray sheep, a flock founded by his grandfather, and into which for about 80 years no foreign blood has been introduced. It offered a remarkable illustration of what careful selection can do, observing, as those breeders do, the rules laid down by the founder, that the constitution of the sheep was the first point to be considered in breeding.

On the 30th of August I gave an address to the Adelaide Stockowners and the South Australian Veterinary Associations, illustrating some of the problems I had studied in South Africa with special reference to similar subjects on which I had made observations in Australia.

During the stay in Adelaide, on the 21st of August, a meeting of the State Committee, with Professor Brailsford Robertson in the chair, was also attended. Some leading pastoralists had been invited. The topic of the address was the observations I had made hitherto in my travels through Australia and the problems in which I took particular interest, viz., those associated with deficiency. Before leaving Adelaide, Dr. Bull showed me a case of swelled head in rams, which he had produced in a wether through the injection of a pure culture of *Bacillus oedematiens*, which he previously had isolated from a case in a ram. The case differed in no way from a natural case I had seen in South Africa.

6. Visits in Western Australia.

On the 31st of August, I left for Perth and arrived there on the 3rd September. I was received by the Chairman of the State Committee of the Council, Mr. B. Perry, the Secretary, Mr. L. W. Phillips, by Mr. Murray Jones, the Chief Stock Inspector, Colonel Le Souef, and Mr. G. L. Sutton, the Director of Agriculture. Subsequently Mr. Sutton introduced me to the Minister for Agriculture, who also took a keen interest in my visit.

On the same day, I had a meeting with Mr. Murray Jones and his staff and the problems they were confronted with were explained, as well as the work hitherto done. The discussion was about pleuro-pneumonia, redwater, swine fever, swine plague, &c. The outstanding problem was, however, that of a braxy-like disease, which was being investigated by Mr. H. W. Bennetts, B.V.Sc., an officer of the Department of Agriculture, who had been seconded to the Council for two years. The localities in which it occurred were to be visited by me. Reference was also made to deficiency diseases in cattle and sheep. An outstanding example was mentioned to have occurred in Kellerberrin, where sheep chewing rabbit carcases succumbed to botulism. The so-called Denmark disease in cattle was supposed to be a deficiency disease as well. A visit to this country could not be made owing to the shortness of time at my disposal. In the course of discussion I learned that yellows in sheep, enzootic icterus of South Africa, had been noted at one time in sheep slaughtered in the abattoirs; attention was also drawn to a peculiar cirrhotic liver affection in sheep coming from the north-west. The latter seemed to be analogous to one known under the name of "waterpens" in South Africa. A visit was made to the quarantine station at Fremantle. En route, I had an opportunity of observing some cattle suffering from so-called rickets, generally believed to be caused by the eating of young *Macrozamia* fronds. It was evident that the disease was not true rickets.

In company with Mr. Murray Jones, we inspected the area in which, in 1923, rinderpest had made its appearance and which at the time had so promptly been dealt with. The fact that this plague broke out in the first instance in an area that may be compared to a peninsula made it clear that the geographical position was not in favour of a rapid spread of the disease, and hence gave an opportunity for prompt isolation and eradication. I also visited the abattoirs and obtained some information about the most prevalent parasitic infections and other pathological conditions encountered. The opportunity was also taken to see the salesyard at Fremantle, where a consignment of cattle just arrived from the north-west were put up for auction. The oxen were about five years old, in fair condition, taking into consideration the long journey on foot, and the subsequent transport by ship. I was, however, struck by a certain resemblance of these oxen to those of South Africa reared in phosphorus deficient areas. At a meeting with the State Committee of the Council, to which a number of graziers had been invited and which I addressed, the grazing conditions of the north-west were explained to me. A casual observation was made that in that area cattle were often noted to chew bones, at some times more than at others. By this statement, my suspicions that the oxen were reared in phosphorus deficient areas, were well supported. It appears to me, therefore, that the graziers in that portion of Western Australia are confronted with a similar difficulty to that of the South African farmer, that of producing prime beef in early maturing oxen and that of breeding pedigree stock for the improvement of beef cattle under ranching conditions.

In company with Mr. G. L. Sutton, Director of Agriculture, and Mr. Murray Jones, I went to the woolstores of Dalgety and Co. and Elder Smith and Co., and saw there the famous wool of the Murchison. We had some very interesting discussions with the gentlemen who showed us the different types of wool, and questions of nutrition and breeding were particularly discussed. The so-called canary stained wool, a defect not yet explained, was shown to me.

On the 5th September, I gave a lecture to the Royal Society of Western Australia. His Excellency the Governor was in the chair. The meeting was well attended.

On the 6th September, in company with Mr. C. A. Gardner, of the Department of Agriculture, an enthusiastic botanist, I left for the Murchison, the famous sheep country. The party was joined in Mullewa by Mr. Mackenzie Grant. We stayed the same night at Mount Magnet. The following morning we called on Mr. Murray in Windarri. The discussion was mainly about wool and constitution of sheep, and proved to me exceedingly interesting. In the afternoon we proceeded to Wogarno, a station managed by Mr. Mackenzie Grant's son, where we stayed until the morning of the 9th. We were in the so-called mulga country, and the botanical knowledge of Mr. Gardner and the practical experience of Mr. Mackenzie Grant with the plants and trees suitable as food for sheep were most instructive. I obtained a good conception of the country in which the famous Murchison wool is produced. On the 9th we returned by motor and arrived at the station of Mr. Broad in Wagga Wagga where we put up for the night. Shearing was going on at the time and the occasion was made use of to inspect some of the fleeces. On the 10th, we left for Newmarracarra, the home of Mr. Mackenzie Grant. The drive through the country, with Mr. Gardner as a guide to the vegetation, proved interesting. The country may not all be good for sheep, but from a botanical point of view is certainly a prolific field for research. We stayed for the night at Newmarracarra and in the morning we had a look at some of the sheep and horses Mr. Mackenzie Grant was breeding. The company of Mr. Grant was, besides good fellowship, most instructive, he having a bent for natural history, I had no difficulty in discussing with him the various aspects of breeding and the influence of environment on the sheep and wool. With reference to the problems of health, there was very little evidence of trouble in sheep. The blowfly certainly was mentioned to be increasingly troublesome in some seasons. Mr. Murray in Wandarri informed me of the presence of swelled head in rams, and a similar condition in wethers and ewes at certain times of the year. I am under the impression that the latter is due to the photo-sensitizing effects of some plants, a subject to be investigated. When I saw the country at Newmarracarra with its hills and creeks I could not help thinking of it as a likely place for parasitic infection, particularly flukes. I learned there was none of the latter; indeed it was pointed out to me that flukes are not known at all in Western Australia, although repeatedly brought there by sheep introduced from the Eastern States.

On the 11th, Mr. Mackenzie Grant brought us to Geraldton, where I was accorded a civic reception and subsequently a drive was made through the famous Greenough Plain in the company of several gentlemen, including Mr. Roen, who was at one time a sheep and wool expert in South Africa. The growing of lupin was shown to me as an excellent pasture, supporting a large number of sheep for at least a portion of the year. In the afternoon, there was a meeting with graziers. After explaining the object of my visit some discussion ensued. There were apparently no difficulties met with in the growing of sheep. Blowfly and footrot were mentioned, parasites were not known, but from a question concerning the cause of bottle-jaw in sheep, I learned that there are probably parasitic infestations in some part of the country, although, perhaps, not fully realized. We departed the same evening by the midland train and alighted in Gingin in the morning. The break of the journey was made use of for a trip into the adjacent country in which I learned there was a peculiar sheep disease locally known as rickets in lambs. We returned to Moora later in the morning in the company of Mr. Bennetts, who had arrived by the same train, and were received there by Mr. Hamilton of the Roads Board, who drove us in the afternoon over a large tract of country, calling on the way at two stations. On one of these, Cranmore Park, two lambs were shown as having died in the morning and a third one was on the verge of dying. The latter was killed and a hurried post-mortem made. It showed the lesions of a severe gastro-enteritis and the absence of intestinal parasites, suggesting the cause to be some irritant, possibly a plant. It resembled the changes I was accustomed to see in a case of Cape tulip poisoning. In the evening a short meeting was held with graziers. There was little discussion; the time was too short and the opinion was expressed that there were hardly any problems connected with animal health in that district. The experience in the afternoon certainly did not support this conclusion. A question was asked about rickets in animals.

On the following day, Mr. Inglis, of Yatheroo, came to fetch the party. We proceeded to the station, inspecting *en route* some of the pastures belonging to it. The influence of top-dressing was very marked and showed itself in particular in a dominant increase of the dandelion (Cape weed) which, however, was very conspicuous by its absence on the limestone ridges. We also examined a herd of cattle brought here from the north for fattening purposes. They were the same kind as I saw in Fremantle. Yatheroo Station is one on which the so-called rickets in lambs exists, a disease occurring under very peculiar conditions. Ewes that are brought to the pasture throw lambs that remain healthy for the first year, but the lambs of the second year are affected to the extent of 50 per cent., and in the third year to as much as 100 per cent. Ewes removed during a portion of the year to a different country, even for a few months only, throw lambs that do not develop this disease. This practice is regularly made use of and serves as a preventive. The trouble is accordingly not considered to be very important. From a scientific point of view it is, however, very interesting, and even fascinating, and deserves to be looked into. Although the country is deficient in phosphates, the disease cannot be explained as true rickets. If it is really a deficiency it is one not yet explained. The examination of a lamb showed me that the disease is certainly not one of the skeleton; it seems to be one of the nervous system. Indeed, it reminded me of the disturbance said to be caused in cattle by eating *Macrozamia* fronds. It is possible that some cumulative poison is responsible. Mr. Gardner pointed out to me that, ecologically speaking, this country had a definite character. We returned on the 13th to Perth. In the morning of the 14th, I was asked to attend a meeting of professors and lecturers at the University and to give them some suggestions as to lines along which the University could assist pastoral research. I made some suggestions as they occurred to me at the time.

In the afternoon of the same day, in company with Mr. Murray Jones and Colonel Le Souef, a visit was made to Northam to attend a meeting of pastoralists. The usual explanation of the object of my visit was made and those present were asked to bring their problems to my notice. There was a good response and information was obtained about blowfly ravages, deficiency diseases in cattle and braxy-like disease in sheep. On the 15th, Mr. Burges, of Tipperary, took us to his station. We inspected the dairy cattle, a herd certainly with no sign of malnutrition and we also saw the stud rams that were depasturing near the homestead. We inspected the pastures on which braxy-like disease occurred. It was all top-dressed country and rich in appearance. The peculiarity of the disease in appearing in various years in different paddocks and the inconstancy of its appearance were emphasized. We returned to Perth the same evening. On the 17th I left for Beverley in company with Mr. Sutton, the Director of Agriculture, Mr. Murray Jones and Mr. Bennetts. We were received by the Farmers' Association. In the afternoon a meeting was held and a lantern slide lecture given on phosphorus deficiency. Subsequently the meeting was invited to give information about the braxy-like disease, when various gentlemen detailed their experience and observations. After the meeting, one of the stations on which the disease occurred rather frequently was visited. Subsequently, the party drove to Pingelly and, in the evening, to a well-filled hall, the lecture on phosphorus deficiency was repeated. After the meeting, a number of interested pastoralists, with Mr. Weaver in the chair, adjourned to a special discussion of the braxy-like disease, which proved to be very instructive. From the discussion it appeared that there are very few common features in the observations of different men, the experience of one man often being contradicted by that of another. However, I realized the seriousness of the position, and the necessity for further and more extensive research. On the following morning a station, on which the heaviest mortality occurred in this district, was visited, when it was pointed out that the disease occurred under all pastoral conditions, in cultivated, top-dressed and scrub country. The latter experience certainly was contrary to that of all other sufferers, and supports the suspicion that more than one disease is responsible for the mortality. In the afternoon the party left for Kellerberrin and in the evening the lantern lecture was delivered for the last time to a very attentive and large audience. We were in the country where phosphorus deficiency was most marked, where even sheep had been found chewing bones and succumbing to botulism. There was some discussion on the subject. Mr. Sutton, who had brought a lantern with him, assisted in the projection of the slides. On the 19th we returned to Perth. Mr. Gardner had joined the party the previous night, and *en route* some interesting botanical and ecological features were looked into. On the way back, a short visit was paid to the Muresk Agricultural College. We arrived in the evening in Perth.

On the 20th I left Perth for Melbourne, where I arrived on the 24th of September.

III.—AUSTRALIAN PROBLEMS IN ANIMAL HEALTH.

In discussing the problems, I am following the order as outlined in the beginning of this Report. Reference will be made to the work already done and brought to my notice. Suggestions will be made at the same time about further work and its extension as they occurred to me, with the reservation that it is impossible, at this juncture, to form an exhaustive or final opinion as to what further investigations should be carried out. There is a group of diseases which cannot be classified at present, as their causes are not yet known. They will be dealt with separately.

1. Diseases due to Micro-organisms.

(i) *Pleuro-pneumonia in cattle.*—The present position is that this disease still presents a great menace to Australia. It would appear that it has established itself permanently in Queensland and in the Northern Territory, where it has become enzootic. If my information is correct comparatively little damage is noted in the area mentioned, and apparently a certain degree of immunity is present in cattle that have been exposed from early life to the infection. Usually, when cattle are placed on the stock routes, the disease makes its appearance, and slaughter-oxen from the Northern Territory and Queensland are admitted into all the States under certain precautions (including quarantine measures); but owing to the fact that apparently healthy oxen are frequently carriers of the infection, the disease is often transmitted to the clean cattle with which the former come in contact, and outbreaks may then occur in susceptible stock with fatal results.

Pleuro-pneumonia is a disease that is amenable to eradication and this has been achieved practically in all States of Western Europe, America, and also in the Union of South Africa, where at one time the problem seemed to be insoluble. The difficulty in Australia, I was informed, lies in the impossibility of a complete muster of the cattle in the large runs of the north. In any process of compulsory inoculation or slaughter, there would always be cattle left out that would maintain the infection. It is to be foreseen that with closer settlement of the area and particularly fencing, the opportunities for a final eradication will be increased. In the absence of a Commonwealth Act dealing with stock diseases, the task of combating pleuro-pneumonia is left to the different States. It does not appear to me that it is a function of the Council to study the problems of pleuro-pneumonia eradication ; it is one of the duties of the administrative officers. At the present time further research work might, however, lighten the task of handling the position as it stands at present and is likely to remain for some time ; help would be afforded by testing the methods now advocated, and by biological tests for the detection of the carriers as they have been evolved in Germany in form of the complement fixation test, and by F. Walker, of Kabeti, Kenya, in the form of the conglutination test. The latter test has been used successfully in Kenya in combating this disease. Professor H. A. Woodruff and Mr. T. S. Gregory have in this country tested the complement fixation test with promising results, and a publication has appeared in the quarterly Journal of the Council, Vol. I., No. 2. The method adopted for the protective inoculation of exposed cattle appears to be the original one, namely making use of the serous liquid obtained from an acute case. The modern method makes use of pure cultures, which are relatively easily obtained and which allow the production of large quantities of virus. This subject has received attention by the Division of Veterinary Research of New South Wales. In view of the difficulty often experienced in obtaining reliable virus this research should be accelerated. It would be advisable that the two lines of research, viz., diagnosis and inoculation, should be continued and carried out by one and the same officer, or at least by officers in the same laboratory. It would save material and time. Since the disease is a contagious one, and inoculated cattle are a potential source for the contagion, well isolated stables would be required and localities should be selected where contact with healthy stock is excluded.

(ii) *Tuberculosis in cattle* is a disease that has been mentioned to me by all chief stock inspectors and meat inspectors. Accurate statistics are, however, not available and those of slaughterhouses do not represent the true situation. It appears that dairy herds are sometimes infected to a considerable degree. The system of pasturing dairy cows day and night and only bringing them into the shed for milking purposes is one that has not favoured the spread of this disease in the way made possible when the cattle are stabled all the time or at least by night. In view of the fact that in all States the improvement of dairy cows is a definite policy of the Department of Agriculture and that the disease is limited to a relatively small number of individuals, a national policy of stamping out would be indicated. This is, however, not a function of the Council. Research in the direction of testing the different methods as advocated in the different countries of Europe and America might, however, be suggested, although it certainly is not of pressing need. The Council is interested at the present time in some experiments being undertaken by Professor Woodruff and Mr. Gregory at the University of Melbourne Veterinary Research Institute to test the value of the Calmette-Guerin vaccine for its immunizing powers. The immunity so obtained was to be tested with virulent tubercle bacilli. I had the opportunity of seeing the results of this latter test. The vaccinated calves apparently were not protected against the injection of virulent tubercular culture. It appears to me that this test is too severe and does not allow any deduction as to the value of vaccination of calves exposed to the natural infection. It seems that this question is not of a pressing nature in Australia. It probably will be settled elsewhere.

(iii) *Tuberculosis in pigs.*—Comparatively little information has been obtained about this disease. Since tuberculosis in pigs can be of different types, viz., human, bovine and avian, it would be advisable in Australia to begin research in this direction. For this research the abattoirs could supply the necessary material and the work might even be carried out in the laboratories of such abattoirs as possess them.

(iv) *Contagious abortion in cattle.*—The presence of this disease was mentioned by all chief stock inspectors and some graziers. It is not exactly known to what extent it is present and no definite policy is accepted anywhere to deal with it. In the present state of our knowledge, advice as to the best ways of dealing with it is difficult. The use of live culture is either not advocated or is prohibited and there is difference of opinion about the value of dead or devitalized culture. The subject has received some attention from the Stock Branch of the New South Wales Department of Agriculture in the laboratory at Glenfield. The problem has received attention practically in all countries where the disease is prevalent. It was discussed at the Empire Agricultural Research Conference held in London in 1927 and it was then urged that the available information should be collected and disseminated. It is difficult to make any other suggestion at the present time.

(v) *Swine fever and swine plague.*—Both diseases are dealt with under the Stock Diseases Act. Valuable research has been carried out in the Glenfield laboratory with reference to the resistance of the virus under various conditions, accurate knowledge of which is of great importance. There is at present much confusion as to the true nature of swine fever and swine plague or contagious pneumonia. Some authorities consider the two diseases to be identical. The experience in Australia seems to point to a different conception. The study of this pneumonia would be a useful piece of research work in this country.

(vi) *Contagious (Streptococcic) mammitis in cattle.*—This appears to be a serious trouble in dairy cows and to be causing considerable economic loss. It is likely that with more intensive dairying and improvement of the dairy cow this disease will increase. Reference to it has been made to me by Mr. Albiston, who has met it in his examination of the bacterial content of market milk in Melbourne. Mr. Carne, of the Veterinary Department, University of Sydney, devoted his attention to its study whilst he was working at the Veterinary College in Alford. He has permitted me to peruse a paper which gave the results of his investigations. In view of the fact that there is considerable discrepancy of opinion as to the identity of this disease with that of Europe and the fact, that in Europe itself (Switzerland) two kinds of streptococci are described, and considering further that this disease has not been noted in South Africa, it would appear that there is still occasion for further thorough research. It would be a suitable subject for the Council to undertake. It should be attacked, however, on a broad basis, with both healthy and diseased cattle in considerable numbers at the disposal of the investigator. Indeed the subject should begin with the bacteriology of the udder of the healthy cow in infected stables, which in itself has far-reaching consequences from a dairying point of view as well. The mode of infection should be determined. It is generally thought that the infection is carried by the milker from animal to animal; other ways should be investigated. Vaccination with streptococcus vaccine is now often resorted to with indefinite results. Preventive measures can only be suggested when the cause and the way of infection are clearly established. The subject has also received the attention of Dr. Seddon, of the Glenfield laboratory, who interests himself at the same time in other forms of mastitis that occur in this country (pyobacillosis, *B. lactis aerogenes*, &c.).

(vii) *Actinomycosis.*—This disease also is dealt with under the different Acts. My attention has been drawn to a rather frequent occurrence of actinomycosis in the udder. The opinion of experts in this country is still held that the disease is an infection caused by the Ray fungus. In view of the opinion now accepted in some parts of Europe that actinomycosis is not at all a fungus disease, but one caused by bacteria, a bacillus in the case of bone actinomycosis, and a diplococcus in the case of the tongue actinomycosis, a revision of the subject deserves attention also in this country. Both Mr. Albiston and Mr. Carne have interested themselves in this problem. In my opinion a systematic investigation should be made of all lesions that are now described as actinomycosis.

(viii) *Caseous lymphadenitis in sheep.*—This condition is of great economic importance, since its presence prohibits the marketing of mutton in England. The cause is generally attributed to the presence of the so-called Preisz-Nocard bacillus. Mostly old sheep are infected, but I have been informed that lambs also are sometimes affected. Pastoralists and farmers complained but little about it; it does not visibly affect health. It may be accepted that all the lesions described as caseous lymphadenitis are caused by one and the same bacillus. Further research to establish this definitely would be advisable. The great object in view is, of course, the prevention and possible eradication of this disease.

For this purpose it would seem necessary to study two aspects, the one to determine the natural and usual mode of infection, and the other the possibility of immunity. *A priori* the latter aspect seems to offer little hope, because it is a chronic infection like tuberculosis. Since, however, in the latter disease a certain degree of immunity can be recognized, this possibility should not be lost sight of. It appears to me that investigations should commence in the field, a flock should be kept and attended to in the usual way, but accurate attention paid to each particular animal as to its history in the different operations it had undergone, controlling the results at intervals by post-mortem examinations. Use should also be made of the abattoirs, and the carcasses should as far as possible be traced back to their origin, in order to obtain more information about climatic and telluric conditions that may be associated with the habitat of the organism and so lead to clues for further investigations.

The subject is receiving at the present time the attention of Dr. Seddon, of the Glenfield laboratory, and Dr. Bull, of Adelaide. Mr. Carne, of the Veterinary Research Institute, Sydney, is also interesting himself in it. Caseous lymphadenitis deserves certainly the full attention of the Council and justifies the occupation of more than one investigator.

(ix) *Footrot in sheep.*— This disease plays apparently a very important role in some parts of the country and at various seasons. Although existing in South Africa it never came up as subject for research. It deserves attention in this country. Senator J. B. Guthrie, in a private letter to me, estimates the annual damage to be £2,000,000. There exist apparently different forms of the disease and probably they are of different aetiology. This has, however, as far as my knowledge goes, nowhere been satisfactorily cleared up, although the bacillus *B. necrophorus* has been found in many instances. Officers of the Stock Branch in New South Wales have collected a considerable amount of information. It appears to me that an extensive bacteriological examination is essential as are transmission experiments to determine the contagious nature, which is accepted in some instances. The question of immunity should also be approached. It is a subject that should interest the Council.

(x) *Redwater in cattle of Queensland, Northern Territory and Northern Western Australia.*—The cause of this disease has apparently been settled to be *Piroplasma bigeminum.* There seems to me, nevertheless, sufficient reason for further investigation. In Africa, in South America, in Texas and in Asia, there is frequently associated with piroplasmosis another infection, viz., anaplasmosis. It has never been described in Australia. From the evidence placed before me, this view is apparently correct, but it requires confirmation. The introduction of anaplasmosis into a tick-infested area would not be without serious consequences. From the examination of blood smears submitted to me in Yeerongpilly I have, however, reason to believe that the blood parasite, *Piroplasma mutans*, now described as *Theileria mutans* is present and has so far been overlooked. It would appear that the late Dr. Dodd, at one time an assistant of mine in South Africa, has observed its presence but expressed a very reserved opinion. This fact also should be cleared up. Besides, it will be necessary to make sure that there is only one species of *Piroplasma* responsible for the disease and not more, there being several species known at present. These aspects seem to have mainly an academic interest, but further investigations may not be without practical result. The question of immunity and of vaccination should again be studied, since there have been observations of breakdowns both in naturally acquired and artificially transmitted immunity. The drug trypanblue, which in South Africa and elsewhere has given such excellent results, should be re-tested. This might have immediate far-reaching consequences. There is at present no veterinarian available in Australia who has sufficient experience in the parasitology of the blood, and I would recommend either the appointment of an experienced officer from Africa to solve these problems or the sending of an officer from here into one of the African laboratories, e.g., Kabete, in Kenya Colony, East Africa.

(xi) *Miscellaneous infectious diseases of secondary importance.*—Pyobacillosis of pigs, arthritis in lambs and pigs, scabby mouth in sheep (Pseudo-variola of France and Africa), suppurative otitis in pigs, granular vaginitis in cattle, necrotic enteritis of pigs, spirochaetosis in fowls, bacillary white diarrhoea in chicks, mycotic dermatitis in sheep, malignant oedema, tetanus, blackleg, etc. My attention has been drawn to these conditions by Dr. Seddon. They are at present studied by him and his staff. Granular vaginitis assumes occasionally widespread proportions. It interferes sometimes with conception and produces temporary sterility. It is amenable to treatment. The causative factor has never been properly established. Fowl diseases are of great economic importance, and have caused the establishment of special research divisions in various countries, viz., South Africa, England, and the United States of America, and similar attention may be necessary in Australia. The paucity of information available to me about the prevalence of these fowl diseases does not permit me to make any special recommendation, but the Council's attention should be drawn to them. They might form suitable additional subjects to be studied in a central laboratory and to fill in slack periods in the investigation of the larger subjects.

2. Parasitic Infestation.

(A) ENDOPARASITES.

The parasites that have been brought to my notice can be grouped according to habitat.

Lungs: Lungworms (*Dictyocaulus filaria* and *Synthetocaulus rufescens*).

Liver: Fluke (*Fasciola hepatica*), hydatid (*Echinococcus granulosus*).

Intestinal Canal: (i) Stomach worms: *Haemonchus contortus, Ostertagia ostertagi* and *circumcincta, Trichostrongylus extenuata, T. instabilis, Nematodirus filicollis, Trichuris ovis* (the latter two seem to be of little importance); (ii) lumpy guts (*Oesophagostomum columbianum*), (iii) Cestodes in sheep, Ascaris in pigs.

Peritoneal cavity: *Cysticercus tenuicollis* (apparently of little importance anywhere).

Sinuses of head: *Oestrus ovis*, the sheep botfly.

(i) *Lungworms.*—In all the States my attention has been drawn to the presence of lungworms. They appear to occur mainly in younger sheep and to cause appreciable damage. They are of relatively little importance in South Africa and accordingly my division there was never pressed to undertake investigations. The life history of this parasite has been worked out to some extent in Germany, but as far as I am aware it has not been confirmed in other countries; nor is it completely known. As preventive measures are largely based on the bionomics of the parasites, it would be advisable to undertake the study in this country, where the worm does so much damage. Considering the fact that carbon tetra-chloride is very effective in ankylostoma infections, and also in fluke, it would be advisable to give this treatment primary consideration in cases of lungworms as well.

(ii) *Liver fluke.*—The fluke has received full attention in Australia. and publications about treatment of infected sheep and the destruction of snails have been made by Dr. Seddon and Dr. Clunies Ross. It appears to me that here also is room for further investigations, with particular reference to establishing how many, and at what intervals, dosings are required to keep the sheep free from these parasites. Such work might lead to the establishment of a method of eradicating the infection from a pasture in the presence of the snails, where the eradication of the latter is difficult or impossible. It would at the same time be necessary to determine the longevity of the snails concerned so as to determine the length of the period over which the treatment of sheep would have to be continued. Flukes appear to be absent in Western Australia and the reason for this interesting fact should be explored. I understand that it has not yet been definitely determined whether the snail responsible in Tasmania is identical with that on the mainland. The effect of tetra-chloride in cattle suffering from mineral deficiency has received special attention at Glenfield.

(iii) *Stomach worms* are found in all States, but so far the prevalence or the importance of the various species has not yet been determined, and so far no attempt has been made to locate their distribution. It would appear that *Haemonchus contortus* is very prevalent but almost always associated with *Ostertagia* and often with *Trichostrongylus*. What has particularly struck me is the relative scarcity of worm infections in pastures where they could be expected according to my experience in South Africa, a phenomenon that apparently stands in some relation to the climate and the topography of the various regions; probably the summer rain and heat being more favorable for their development in South Africa than the humid winters and dry summers in Australia. Effective treatments are available for one kind of stomach worms, viz., *Haemonchus contortus*, but not yet for the others. The study of the life history of those parasites, that have not yet been determined is advisable, particularly in the case of *Ostertagia*. Artificial infestation of sheep in the laboratory would supply suitable material for the study of different drugs, a method that proved most successful in South Africa. The summer rains coupled with the summer heat seem to be more favorable for the breeding of worms in the northern districts of New South Wales and Queensland, particularly the coastal areas. This is probably the reason for the presence of the nodular worm in those parts, where it is doing considerable damage, but its exact distribution is not known. One of the first things to be undertaken is a survey of the distribution of the parasites in Australia. There exists at present a census by Dr. Georgina Sweet, dated 1908, of the parasites in Australia. This should be brought up to date with indications of the localities in which the parasites are present. The reason for the geographical distribution should be ascertained, i.e., the relation of parasites to environment should be studied.

(iv) *Tapeworms* in this country, as well as in others, seem to be frequently found in lambs. The species should be determined and their distribution established. Their life history has not as yet been cleared up, and Australia might offer opportunities to do so. The parasitologist who succeeds will gain considerable credit for his work. Australian workers might just as well be in this race.

The study of parasites at present is attended to by Dr. Clunies Ross, in co-operation with Dr. Seddon and his staff. Mr. Bennetts, in Western Australia, has likewise devoted his attention to them. The scope of the work is, however, so large that there is room for even a larger staff. The hydatid infestation of dogs has admirably been dealt with in a thesis by Dr. Clunies Ross that deserves to be printed and widely distributed.

(v) *Ascaris in pigs.*—To the ascaris infection in pigs particular attention should be paid, since this infection, in my experience, can make successful pig-rearing impossible.

(vi) *Oestrus ovis* has been stated to have made its appearance in Queensland and Western Australia. However, no definite trouble has been associated with this parasite. Its distribution and seasonal occurrence should be studied. It is, however, of limited economic importance.

(B) ECTOPARISITES.

I include here the buffalofly, the tick, the blowfly and the worm nests in cattle. Keds and lice are of less importance, since there exist satisfactory methods for dealing with them.

(i) *The buffalo fly* (*Lyperosia exigua*) is apparently in the first instance a problem for the entomologist, and I understand biological methods of control are suggested and have been to some extent already studied. Surveys of the distribution of the fly have been made by Mr. Murnane, an officer of the Council. These surveys should be continued and the reasons for the apparent existence of natural barriers explained. The control by biological means may fail and other ways may have to be looked for. The possibility of quarantining and systematic evacuation of certain areas in order to starve out the flies should be studied. A close co-operation with the Division of Economic Entomology should be maintained. The question of breeding cattle tolerant to the fly deserves attention; but as the crossing may mean the importation of sires from overseas, a warning should be given as to the potential dangers of introducing other diseases at the same time, and this particularly in a tropical and tick-infested area.

(ii) *The cattle tick* (*Boophilus australis*).—Considerable work has been done in Australia in the past, but only recently has a comprehensive study of the life cycle of the Australian tick come to my notice (the thesis of Dr. G. Legg, D.V.Sc., in charge of the Townsville Stock Laboratory). The study of the destruction of the cattle tick is at present in the hands of a special committee, the Cattle Tick Dips Committee. Efforts are made to determine the most effective method to destroy the ticks. Modifications of strength of arsenical dipping fluids, the addition of adjuvants and the determination of the most suitable intervals for dipping are studied. Recently I had the privilege of perusing a report by Dr. Legg on the results of his dipping experiments, which throw some new light on the question. There is, in my opinion, still further room for investigation with particular reference to catching that tick which hitherto in almost all trials has escaped destruction. In other words, the cause of the survival of some ticks that reach maturity after having gone through dips should be closely studied. The question is of great importance. Since a policy of tick eradication throughout the infested areas seems at present to be out of consideration, for the same reason as that outlined under the discussion of pleuro-pneumonia, the question has been asked whether a tick-proof race of cattle could not be evolved by crossing with Brahma cattle which are apparently much less attacked. Attention should be given to such a possibility, but, as in the case of a similar proposition concerning cattle tolerant to buffalo-fly, a warning should be expressed against the danger of introducing cattle from countries in which such diseases as surra, rinderpest, foot and mouth disease, etc., exist. What might be suggested at present is to study whether there do exist amongst the cattle in the areas certain strains that are more tick resistant than others and whether there is sufficient information to show, that such resistance is a hereditary factor. These investigations can, of course, be carried out only in tick-infested countries.

(iii) *The Blowfly*.—The question of the blowfly is probably the most important one and one to which primary consideration should be given. I was informed that the annual damage caused by its ravages amounts to £4,000,000, and that this sum is probably under-estimated. Several species of flies are known to blow sheep. The subject is one that interests the entomologist as well, and it is proposed that the study of control by predatory insects be undertaken. The problem interests the veterinarian from a different angle. It has been brought to my notice that as a rule only certain sheep are blown and that there are certain factors that predispose sheep to the attacks of the fly. Some station-owners even go so far as to say that this disposition runs in certain families. This peculiar disposition is the point of interest and should be followed up. Investigations in these directions are in hand by an officer of the Council, Mr. Mulhearn, in Nyngan, under the direction of Dr. Seddon.

It appears to me that here is a field for a bio-chemist as well, who should study the nature of the particular substance that attracts the fly, and whether such substances can be traced in the living sheep. There is also room for bacteriological work. Infested sheep often die rapidly, and death seems to be due to the absorption of some toxic substance through the sores caused by the presence of the fly larvae. These toxogenetic saprophytes should be studied. In this connexion an observation made in South Africa that blowflies carry the infection of botulism from carcass to carcass is interesting. That the merino sheep should be particularly predisposed is remarkable, but it appears to be only within the last 25 years that this condition has been brought about. In this respect the observation in South Africa is of some importance. The blowfly pest in that country is only of recent occurrence, being subsequent to the improvement of the South African merino, although blow-flies have always been present in that country. A station for the study of the blowfly is essential. There must be a good supply of sheep ; indeed sheep-breeding should be undertaken there and the problem studied from all angles. Should it be true that certain sheep are never attacked by the fly it would be advisable to ascertain whether such an immunity is a hereditary factor.

The treatment of sheep, both from a preventive and curative point of view, has secured considerable attention, and at present trials in this direction are still carried out at Nyngan. These should be continued and new suggestions will probably arise once the bio-chemist can tell us what are the fly-attracting substances.

(iv) *Onchocerca gibsoni*, the cause of the worm-nests in cattle. This has been a subject of repeated investigation and by a number of investigators. Although the presence of the worm does not appear to cause any malaise, it interferes considerably with profitable exploitation of the beef. Infested briskets are rejected. The trouble was first noted in Queensland and in the northern parts of Australia. Recently within the last two years, a focus of infection has been established in Victoria, namely in Gippsland, along the coast, in the neighbourhood of Foster. It would, therefore, appear that the trouble is not limited to warm climates exclusively and the possibility of further spread is possible. It is generally assumed that the infection of an animal takes place through the agency of an intermediary host and many attempts have been made to trace it. The observation by Dr. G. M. Heydon, in Townsville, that *Onchocerca* larvae can be found in the skin, an observation supported by Mr. G. MacLennan in material obtained from cattle in Foster, is of considerable importance. Search for the intermediary host should be continued. It appears to me that the right procedure is for one or two men, an entomologist and a parasitologist, to settle down in that area which shows the maximum of infection, to observe what are the biting vectors (ticks, diptera, lice, mites) and to examine these for the presence of worm larvae. In this way, indications would be found on which could be based transmission experiments outside the infected area to clinch the evidence.

3. Intoxications.

(i) *Botulism and para-botulism.*—This subject has received considerable attention from Dr. Seddon, of Glenfield, and the nature of impaction paralysis, dry bible, Midland cattle disease and forage poisoning has satisfactorily been cleared up. The relation of phosphorus deficiency as an indirect cause has also been demonstrated in this country. The subject is still receiving the attention of Dr. Seddon and his officers. There is still room for more research, which is, however, of a less pressing nature, though of practical importance.

(ii) *Toxic plants.*—A great amount of work has been done on this subject in Australia, and already a considerable number of plants have been found to possess either specific toxins, often producing clinically well-defined diseases, or to act by photo-sensitization on the non-pigmented portion of the skin, or by the production of hydrocyanic acid under peculiar and not yet completely understood conditions. There are as yet a number of plants suspected to be toxic, the toxicity of which has not been proved or disproved. Western Australia and Queensland seem to have in this respect their own problems. The subject has already received attention by the Council, and work is being carried out in co-operation with the University of Sydney (Physiology, Chemistry and Pharmacy Departments) and the New South Wales Stock Branch and Botanists. The investigations into Kimberley horse disease, carried out in co-operation with the Western Australian Department of Agriculture, have resulted in the discovery of its cause. There seems to be some evidence that whitewood is present in areas where the disease has not been noted. It is possible, as I have found to be the case with several toxic plants in South Africa, that not all plants of the same genus are toxic, that they are toxic only in certain years and not in others, nor at different times of the year. These aspects deserve to receive further attention from the standpoint of possible variability in the toxicity of whitewood. The Western Australian Department of Agriculture is also interested in other toxic plants.

A carefully planned programme should be drawn up and systematically carried out. The symptomatology and pathology should be studied. Since the eradication of some of the poisonous plants may prove to be possible by methods of biological control, the entomologist should be interested in it as well, and a valuable assistance would be a map indicating the geographical distribution of toxic plants in the different States.

The preliminary feeding experiments could be carried out in laboratories or stations nearest where the plants occur, but confirmation of results should be undertaken in the main laboratory as well. It appears to me that many of the diseases occurring sporadically in different animals are probably caused by toxic plants and not at all suspected as yet by pastoralists or farmers.

(iii) *Mineralized drinking water.*—This subject is of importance to Australia. Certain waters render animals ill or unthrifty. Systematic experiments as to the effects of minerals contained in bores should be carried out. The subject has also some relation to parasitic infection since some pastoralists claim that sheep drinking in certain bores become free from intestinal parasites.

4. Deficiency Diseases.

The presence of osteophagia in cattle over vast portions of Australia is one of the features which struck me in my travels. Rickets in young and osteomalacia in adult cattle came to my notice. The existence of botulism in cattle and sheep is undoubtedly connected with this deficiency. The problem is at present sufficiently well known for it to be possible to suggest preventive measures, and such have already been adopted in the supply of licks and by top-dressing. I have given particular attention to the effect of top-dressing with superphosphates, and the almost universal striking response to this treatment indicates the importance of this subject. Deficiency does not, however, always show itself in animals as a definite pathological condition ; phosphorus being a limiting factor in growth and production of beef and milk, a non-profitable animal results. Besides this, deficiency often is the cause of a general unthriftiness and unhealthy appearance and frequently the cause of sterility in stock. What has particularly struck me however, is that in some areas, particularly in Tasmania, where this deficiency was present in an exaggerated measure in cattle, the sheep running on the same pasture were producing the finest wool. That such sheep may show signs of deficiency in their skeleton was shown to me on post-mortem examination ; besides I have been told that breaking of ribs in these animals is not an infrequent occurrence. Accordingly it appears to me that this subject should be approached from a wide view and in particular from that of the quantity and quality of wool. Here is a vast field for research. The subject of nutrition, I understand, is one which is under the care of Dr. Brailsford Robertson in Adelaide. There is room for more than one worker, and a judicious division of labour between purely nutritional problems and those that affect health and productivity could be laid down. Recently, Dr. H. H. Green, of my former Division in South Africa, has shown that the examination of the blood for phosphorus content gives a valuable aid in the determination of deficiencies in animals. These investigations should be followed up in Australia and particularly in connexion with the breeding of sheep in the various areas, it being well known that the qualities of wool apart from breed are related to environment, the outstanding and most important factor of which seems to me to be this phosphorus deficiency.

It would appear from information received from Mr. Philp that in King Island a condition in cattle has been diagnosed that corresponds to the iron deficiency noted in New Zealand. This certainly requires confirmation.

5. Diseases the Causes of which are as yet unknown or not confirmed.

Cattle Diseases—

(i) Haematuria of Mount Gambier District (South Australia).
(ii) King Island coastal disease.

(iii) Scours in calves.
(iv) Denmark cattle disease.
(v) Sterility in cattle.

Sheep Diseases—

(vi) Enzootic icterus (yellows).
(vii) Swelled head in rams.
(viii) Braxy-like disease in Western Australia.
(ix) Black disease.
(x) Plethoric toxaemia (pulpy kidneys).
(xi) Fatty liver (twin disease of Tasmania).
(xii) Cancer.
(xiii) Balanitis (pizzle) in wethers.
(xiv) Opthalmia.
(xv) So-called rickets in lambs in Western Australia.
(xvi) Sterility in rams and ewes.
(xvii) Disturbances in the growth of wool, skin affections, and faults in the wool itself.

Horse Diseases—

(xviii) Ulcerative enteritis in Tasmania.
(xix) Waratah disease in Tasmania.
(xx) Gilbert River disease in Queensland.
(xxi) Stringhalt.
(xxii) Western blindness.
(xxiii) Epitheliomata.

Pig Diseases—

(xxiv) Paralysis in pigs.

The economic importance of the diseases enumerated and whose cause is as yet not, or only incompletely, known varies considerably, but there is no doubt that some are of extreme importance to the localities in which they occur. I shall discuss them in the order in which they are enumerated.

Cattle Diseases.

(i) *Haematuria or redwater* in cattle of the Mount Gambier district is already under investigation by Mr. G. C. Dickinson, an officer of the Council working under the direction of Dr. Bull, Adelaide. No report has so far been published. It seems to me that Mr. Dickinson works under a disadvantage in being placed far away from the disease. What is required is a laboratory in Mount Gambier itself and preferably on one of the affected farms. It would be advisable to take over one of the farms and settle down on it. The remarkable coincidence of phosphorus and manganese deficiency in this area should not be lost sight of. Feeding experiments seem to me to be necessary both inside the affected areas and outside. A clue for further research may then be found.

(ii) *King Island disease.*—There are at least two different conditions in this Island one akin to the iron deficiency of New Zealand (the one referred to above) and the other a peracute disease of cattle not even named. There should be placed on the island a veterinary officer, who would make the preliminary observations and collect material for pathological examination on a well-defined plan.

(iii) *Scours in calves* is described in all countries. The causes vary. More clinical observations and post-mortem examinations will be necessary and examination of material should be made whenever opportunities, occur.

(iv) *Denmark cattle disease.*—This is of considerable importance to the Denmark country in Western Australia. It is suspected of being a deficiency disease. It is under investigation by the Stock Branch of the Western Australian Department of Agriculture, and some experiments have been carried out. Collection of material for pathological examination is essential. Indications for further experimental research may then be found. A primary experiment to test for deficiency should be made.

(v) *Sterility in cattle.*—With the improvement of dairy cows, diseases of the sexual organs will occur and increase. A considerable amount of work has been done in all parts of the world, and the causes of sterility vary somewhat. It is advisable that attention be paid to it in Australia also and in connexion with the prevalence of such diseases as contagious abortion, granular vaginitis, and phosphorus deficiency.

Sheep Diseases.

These are of increasing importance and it can be foretold that, with the improvement of pasture and extensive lamb rearing and feeding, new troubles will arise.

(vi) *Enzootic icterus.*—This has been observed in South Africa only within the last four or five years. Work has been carried out but the cause has not been determined. It is suggested that it is of toxic origin. It is at present under investigation at the Glenfield Research Station.

(vii) *Swelled head in rams.*—This has come to my notice in South Africa only in recent times. It is being investigated by Dr. Seddon and Dr. Bull. The latter gentleman appears to be able to produce the condition by the injection of a pure culture of *Bacillus oedematiens*, isolated from a natural case. The question of immunity to this disease has yet to be settled. Should such exist, a protective indication may be possible.

(viii) *Braxy-like disease in Western Australia.*—This disease is widespread and on the increase and gives cause for serious complaints. Mr. H. W. Bennetts, seconded to the Council, is at present investigating it, but he appears to me to be working under disadvantages. He is placed in Perth and has to travel a considerable distance when a case occurs. It seems advisable to place a second man in the district where the disease occurs, preferably on a badly-affected farm, where clinical observations could be made, accurate post-mortems carried out and fresh material collected. Pathological investigations are also essential to this case. The study should also be approached from the biochemical aspect. Mr. Bennetts suspects an infection with *B. welchii*, and should this prove to be so, the question of immunity will crop up and with it the possibility of an immunization method.

(ix) *Black disease.*—This disease seems to be associated with the presence of fluke. Mr. A. W. Turner, of the Council, has demonstrated the presence of *B. oedematiens* in the affected portion of the liver. Reproduction of the disease under artificial conditions will be required to clinch the evidence. Immunity in this infection may be expected. If the association with liver fluke proves to be a constant and necessary one, the disease must of necessity disappear with the eradication of the fluke.

(x) *Plethoric toxaemia*, also known as *pulpy kidney*, is a very obscure condition. It is said to occur in England also, and forms there a subject of investigation in the Cambridge Veterinary Laboratory under Dr. Buxton. It appears to me that a thorough pathological examination of all viscera should be made before experimental investigation can be suggested. The subject should also be approached from a biochemical point of view.

(xi) *Fatty liver* (twin disease of Tasmania). This apparently is a widespread complaint, occurring in Tasmania and in the eastern States of the mainland. It causes considerable loss in Tasmania and an early start on this problem is indicated.

It also appears to be connected somehow with improved pasture and the system of depasturing and feeding. In the first instance, material for pathological examination should be collected. Mr. Oxer, of the Tasmanian Stock Department, is at present interesting himself in this disease. It seems to me that the problem should also be attacked from a biochemical point of view. The fact that it is always associated with pregnancy should give a clue for research by analogy with diseases known in human medicine.

(xii) *Cancer in sheep* is a minor complaint. Pathological examination is suggested to obtain a clear understanding as to whether it is really a malignant growth.

(xiii) *Balanitis* or *pizzle* in wethers seems to be a serious complaint in some places. There is a rough and ready remedy by splitting the prepuce, when an improvement takes place. Such sheep fetch low prices on the market. It is apparently infectious and should be approached from the bacteriological point of view.

(xiv) *Ophthalmia* or *blight* appears to be infective. It is amenable to treatment. The causative agency is not known. It is a subject for a bacteriologist in the first instance.

(xv) *Rickets* (so-called) in the Moora and Gingin districts of Western Australia. The name is misleading, since it is evidently not true rickets, a disease of the skeleton. A method of prevention is at present in use by shifting the ewes to different pastures during a period of the year. From a scientific point of view, the subject is a very fascinating one and deserves some attention.

(xvi) *Sterility in rams and ewes.*—This seems to me very important. In the case of the rams it may simply be a pathological condition of the sexual organs. It is not likely to be connected with nutritional deficiency, but it may be associated with breeding and then be congenital. Breeders do not like to give information about it, but the fact that to ensure pregnancy in ewes, more than one ram is frequently used with a given number of ewes, would indicate that it is a factor to be taken into consideration. Sterility in ewes is a frequent occurrence ; as few as 35 per cent. of lambs are sometimes marked in some areas. It appears to be nutritional and varies according to seasons. It is not quite clear whether it is a real sterility or only a deferred oestrum influenced by the conditions of environment.

(xvii) *Disturbances in the growth of wool* may be the result of disease of the skin or of malnutrition. Their causes should be studied. This refers in particular to stained wool (the canary stained wool), the causes of which are not understood as yet. The subject may be one for a biochemist and a bacteriologist.

Horse Diseases.

(xviii) *Ulcerative enteritis* in Tasmania is possibly connected with parasitic infestations and should in the first instance be approached by a parasitologist. It does not seem to be of great economic importance.

(xix and xx) *Waratah disease* and *Gilbert River horse disease* seem to be related to the Kimberley horse disease ; the Gilbert River disease is most likely identical. I understand that, in Tasmania, whitewood (*Atalaya*) the cause of Kimberley horse disease, is not present. In the country where the Waratah disease occurs species of *Senecio* are found, and it is suggested that they may be the cause. These questions could easily be settled. The latter disease seems not to be of much economic importance.

(xxi) *Stringhalt* appears enzootically in certain areas and is accordingly suspected to be of toxic origin, due to some plant. It is under investigation by Dr. Seddon. Mr. Gunn, of the Sydney Veterinary College, is also interesting himself in it. The importance of the subject lies in the consequences its solution may have from a scientific aspect similarly to that of blindness in horses.

(xxii) *Western blindness in horses.*—According to the report of Dr. Seddon on this disease, a degeneration of the optic nerve is found. The paddy melon (*Cucumis myriocarpus*) is associated with this blindness, but feeding experiments have failed. In view of the pathological changes it produces and the importance it has from a scientific point of view, further efforts to find the cause are certainly advisable.

(xxiii) *Epitheliomata* are stated to be identical with habronemiasis or worm infection of the skin in horses. It has a scientific interest, but my attention has not been drawn to its economical importance.

Diseases in Pigs.

(xxiv) *Paralysis* in pigs is apparently an important subject. It is being studied at present by a Council officer, Mr. W. A. Carr Fraser, at the Glenfield Research Station from the point of view of deficient diet. A thorough study of the pathological anatomy should first be made, since so far the experiments have given no clue as to the cause.

Remarks.

It is evident that not all of these diseases are of equal economic importance, but some of them are of great scientific interest. No great effort or expense is required to study them. They may be approached as occasion offers and undertaken as secondary work of investigators in those laboratories near which they occur, or in the central laboratory which has a complete outfit for all branches of investigation.

6. The Healthy Animal.

Attention has already been drawn in the introduction to the necessity of more knowledge about the healthy sheep. This refers particularly to the sexual cycle of the merino. The fact that it is an animal of less fecundity than the other breeds of sheep is, in my opinion, sufficient reason for studying its sexual behaviour. The fecundity appears to be easily interfered with by changes of environment, but more knowledge of the causes is required. But, in order to gain this knowledge, it is necessary to know, first of all, the normal behaviour. English sheep and also South African native sheep have a restricted oestrus cycle; i.e., they conceive only at a certain time of the year. With the merino this definite sexual character seems to have changed, and ewes are said to conceive all the year round. The evidence is, however, not clear, and may even be different under various climatic and nutritional conditions. Besides, the succession of the oestrus cycle should also be definitely settled; it is admitted to be 21 days, but here also, opinions differ somewhat. The study requires a careful examination of the sexual organs, particularly the ovaries, and is one for a physiologist trained in this direction. It probably would occupy one man for a number of years.

The study of the normal animal refers also to the development of the wool fibre, the histology of the skin and the physiology of growth. Not enough is known as yet. The information in such books as Bowman, *Structure of the Wool Fibre*; or Mathews, *Textile Fibres*; or Hawkesworth, *Australian Sheep and Wool*, is inadequate. The example of South Africa, where a special effort is made to study this aspect, should be followed. The publications of Professor Duerden are inspiring. I consider the study of the normal sheep under Australian conditions of equal importance to the study of its diseases. It will lead to clearer conceptions and will be useful to the pathologist as well as to the breeder.

Taking into consideration such pathological conditions as toxaemic plethora in lambs and twin disease in ewes, certain aspects of the normal metabolism of sheep should be specially studied. It is work for a biochemist and much fundamental work has yet to be done.

7. Genetics.

Considering the interpretation of health as I view it, it is evident that breeding may be one of the factors that lead to unproductive animals. The possibility has been suggested that sterility in rams may be associated with breeding. Here, therefore, is a field for research. But it will be necessary to consider this aspect from a wider point of view. The Australian flock-master has proved to be a successful breeder; it is generally stated that breeding has been done on scientific lines, based on the principle that like begets like, by selecting the most ideal animals. But no real study has been made on modern principles to ascertain to what extent the Mendelian laws apply, and which of the characters are subject to it and which not. I admit the problem is a vast one, but it should be approached. The least that could be done is to analyse the results so far obtained by a man thoroughly conversant with genetics and then suggest a line of definite experimental research work. I am not competent to advise in this direction; it suffices to draw attention to the necessity for research. The subject has also a direct relation to health, as it affects the inheritance of such factors as are implied in the term constitution and in particular, resistance to certain diseases such as footrot, lungworms, flukes, from which certain breeds of sheep are supposed to suffer less than others. It has also reference to a possible immunity against blow-fly infestation and for this reason alone should be studied. The problem of breeding of tick-resistant and buffalo-fly tolerant cattle should also be considered by an expert in genetics.

IV.—DISCUSSION OF THE PROBLEMS AND THE ORGANIZATION.

1. Classification of the Problems.

The subjects have been grouped below according to the particular branch of science to which I would allot them for investigation.

I. Pathological Anatomy.

1. Haematuria in cattle.
2. King Island cattle disease.
3. Scours in calves.
4. Denmark cattle disease.
5. Sterility in cattle.
6. Enzootic icterus.
7. Braxy-like disease.
8. Plethoric toxaemia (pulpy kidney).
9. Fatty liver (twin disease).
10. Cancer in sheep.
11. Rickets in lambs (Western Australia).
12. Ulcerative enteritis (Tasmania).
13. Waratah disease (Tasmania).
14. Gilbert River disease (Queensland).
15. Stringhalt.
16. Western blindness in horses.
17. Epitheliomata.

18. Paralysis in pigs.
19. Toxic plants.
20. Minerals in drinking water.
21. Deficiency in cattle, sheep, pigs and horses.

II. Microbiology.

(Bacteriology, Protozoology, Virus Diseases, Immunology).

1. Pleuro-pneumonia.
2. Tuberculosis in cattle and pigs.
3. Contagious abortion.
4. Contagious streptococcic mastitis.
5. Actinomycosis.
6. Botulism and Parabotulism.
7. Red water in cattle (piroplasmosis) (Queensland).
8. Granular vaginitis in cattle.
9. Scours in calves.
10. Caseous lymphadenitis in sheep.
11. Foot rot in sheep.
12. Arthritis in lambs.
13. Scabby mouth in sheep (pseudovariola).
14. Mycotic dermatitis in sheep.
15. Swelled head in rams.
16. Braxy-like disease.
17. Black disease.
18. Balanitis (pizzle) in wethers.
19. Ophthalmia in sheep.
20. Swine fever and swine plague.
21. Pyobacillosis in pigs.
23. Suppurative otitis in pigs.
24. Spirochaetosis in fowls.
25. Bacillary diarrhoea in chicks.

III. Parasitology.

1. Ulcerative enteritis in horses.
2. Flukes in ruminants.
3. Ticks in cattle.
4. Onchocerciasis in cattle,
5. Buffalo fly.
6. Lung worms in sheep.
7. Stomach worms.
8. Tapeworms in lambs.
9. Blowfly in sheep.

IV. Biochemistry.

1. Haematuria in cattle.
2. Denmark disease.
3. Deficiency diseases in cattle and sheep.
4. Braxy-like disease.
5. Plethoric toxaemia (pulpy kidney).
6. Fatty liver (twin disease).
7. Biochemical research on blood of healthy sheep.

V. Physiology.

1. Sterility in cattle.
2. Sterility in rams.
3. Sterility in ewes.
4. Blowfly in sheep.
5. Development of wool.
6. The normal sexual cycle of the sheep.

VI. Genetics.

1. Sterility in rams and ewes.
2. Tick-resistant cattle.
3. Buffalo fly-resistant cattle.
4. Genetics applied to wool production.

VII. Intelligence or Bureau.

No reference has previously been made to this. In view of the formation of a Bureau of Animal Health for the Empire, the duty of which will be to collect all the information relating to research, it would be advisable to have a Commonwealth Bureau of a similar nature. The duty of the officer in charge would be to collect all the information accumulated in Australia in the past, in the first instance for the benefit of workers engaged in local research. He would supply the London office with all publications appearing in Australia and so strengthen the activities of the Imperial Bureau.

2. The Organization.

The problems have been placed in seven different groups to indicate that the organization should include seven sections. The groups (III.), (V.), (VI.), and (VII.) are self-contained, and in groups (I.), (II.), and (IV.) the subjects are to a certain extent interchangeable, and the members of their staff may be transferred whenever the necessity occurs. These seven sections should have their headquarters at a central institute, and it would be advisable to have this institute in the neighbourhood of the other scientific research Divisions of the Council (Economic Entomology, Economic Botany, etc., etc.), since intercourse with workers in other sciences would be of great advantage; besides some of the subjects are of interest to them as well, and will have to be undertaken in co-operation with them.

3. Problems Proposed for Early Investigation.

A judicious selection of the subjects to be investigated should be made, and in this respect a division of labour could be made with already existing institutes which are not under Council control. At present there are a number of problems under investigation by the Council and research in at least some of them should be continued. It would be advisable to increase the facilities for research on some of them but to abandon others. I propose to enumerate them seriatim with suggestions as to the proposed extension of work or improved facilities.

A. DISEASES UNDER INVESTIGATION.

1. *Haematuria in cattle,* Mount Gambier.—A field station should be established in the affected district. In view of a possible connexion of deficiencies with the cause of the disease, cattle should be fed both on the area and outside the area with food grown on the area and from healthy country. The temporary stables outside the area might probably be put up at the Waite Institute. The investigating officer should be placed in the field laboratory, and the observations at the Waite Institute could be made in co-operation with the Stock Department, which could lend its pathologist for this purpose. I suggest at least ten animals in each lot. An officer of the bio-chemistry section could temporarily be placed in the Mount Gambier area to study certain bio-chemical aspects that may affect the problem. A farm at Mount Gambier might be rented for the purpose, or arrangements could be made with a farmer. A stockman would be required, who could also assist in the laboratory.

2. *Braxy-like disease in sheep* in Western Australia.—Laboratory facilities in Perth should be increased especially for stabling animals. The bacteriological work could be done in Perth. A field officer should be placed in Pingelly, preferably on the worst infected farm. He ought to have motor transport at his disposal to enable him to make daily observations of the flocks and to collect the material as fresh as possible to be forwarded to Perth.

3. *Paralysis in pigs.*—This could be carried out in the central laboratory. Sick pigs should be bought and forwarded to the laboratory. An officer of the pathological section should be entrusted with this work. About ten to twenty sick pigs should be acquired. Further work can only be suggested when the pathology is clearly understood.

4. *Pleuro-pneumonia in cattle.*—This work could be carried out at the central laboratory where facilities exist for the isolation of cattle. About twenty or more cattle should be available in the beginning; more may be required later

5. *Tuberculosis in cattle.*—I suggest this to be left in abeyance for the time being, pending results from other parts of the world.

6. *Caseous lymphadenitis.*—A flock of sheep to be established, sheep-breeding to be undertaken, and field observations made. This work might be carried out at the same station as the blowfly work, but different flocks would have to be used. The flock should be of not less than 500 sheep. One field officer is required, also a temporary laboratory where bacteriological work could be done, and also some stabling for experimental animals. A stockman will be required.

7. *Black disease.*—This problem could be tackled in the central laboratory.

8. *Stomach worms.*—These investigations could be carried out at the central laboratory with about 50 sheep.

9. *Cattle ticks.*—Investigations in the field in Queensland. This subject is dealt with by the Cattle Tick Dips Committee, and no alterations can be suggested at present.

B. NEW SUBJECTS RECOMMENDED FOR INVESTIGATION.

10. *King Island cattle disease.*—An officer of the pathological division to be stationed at King Island during the period of the disease to collect information and material to be examined at the central laboratory. Further investigations can be suggested when more is known about the incidence of the disease and the pathological changes.

11. *Denmark cattle disease.*—A field officer to be placed in the area to collect information and material for pathological investigations. An experiment is suggested to test the possibility of deficiency as a cause. About ten head of cattle will be required in the beginniug. Arrangements should be made with a farmer to obtain his pasture. A stockman will be required. This field officer should be under the direction of the laboratory in Perth, where the necessary primary pathological investigations should be carried out.

12. *Fatty liver (twin disease) in sheep.*—A field officer to be placed in the area most suitable in Tasmania. Co-operation with the departmental officers should be obtained, and material for pathological examination should be collected. An officer of the bio-chemical section should be in attendance temporarily to study certain bio-chemical aspects of the disease.

13. *Toxic plants.*—These investigations could be undertaken in the central laboratory, but the laboratories of Western Australia and Queensland should also be made use of for their respective problems.

14. *Deficiency diseases.*—The pathology of deficiency diseases in all animals to be studied at the central laboratory. The material would have to be collected in various parts of Australia. The subject has also to be dealt with by the bio-chemical section to obtain standards for the purpose of a method by which deficiencies can be diagnosed from the blood.

15. *Contagious streptococcic mastitis.*—This subject should be studied at the central laboratory. Sick cattle should be bought and kept under observation. Healthy cattle will be required for transmission experiments. A stable for 20 to 30 head of cattle will be required. In this problem the pathologist, the microbiologist and the bio-chemist are interested. It would be in charge of a bacteriologist. One stockman is required.

16. *Footrot in sheep.*—A field officer should be stationed in an area where the disease is a common occurrence, for the purpose of making clinical examinations and of collecting material to be sent to the central laboratory, where transmission experiments should be made. About 50 sheep are required for experiments.

17. *Redwater in cattle.*—(Piroplasma and other blood parasites).—These investigations will have to be carried out in Queensland, probably at the Townsville Stock Laboratory, and by an officer especially trained for this purpose. About twenty young oxen should be placed at the disposal of the officer in charge. A stockman will be required.

18. *Lung worms in sheep.*—This work can be carried out in the central laboratory, and could be undertaken by the same officer who is studying the stomach worms. About 50 sheep will be required.

19. *Onchocerciasis in cattle.*—At least one officer, preferably two, one being an entomologist, should be placed in an area where the disease is very prevalent, to make observations of the biting vectors and to examine them for the presence of the worm larvae. Transmission experiments should be undertaken outside the infected area, once a clue has been found as to the possible vector. A temporary field laboratory would be required and some manual assistance will be necessary.

20. *Bio-chemical problems of the healthy sheep.*—This is a subject for the bio-chemical section, and refers to chemical examination of the blood, etc., of sheep under various conditions of nutrition in order to obtain normal standards. This can be carried out at the central laboratory. About ten sheep will be required.

21. *Study of the sexual cycle.*—Since in this undertaking post-mortems will have to be made and material from ewes collected, it will be advisable to undertake this work in the central laboratory, where the greatest facilities will be available. These animals must be kept under conditions as natural as possible, which could be provided on the pasture lands of the station. Once the normal sexual cycle is clearly understood, the abnormal should be investigated. Arrangements will have to be made for this special purpose with pastoralists. A flock of about 200 ewes and 10 rams will be required. Later the work could be linked up with that on blowfly and lymphadenitis. One field officer will be required.

22. *Sterility in rams.*—Material to be obtained by taking flock masters into confidence. An anatomical examination of the sexual organs to be carried out and experiments to be undertaken to restore fertility.

23. *Development of wool.* A histological study of the skin of all breeds of sheep, but especially of the merino, with reference to the growth of the fibre and all abnormalities connected with it.

24. *The study of the disposition of sheep for the attack of blowflies.*—The work should be carried out in co-operation with a bio-chemist. A flock of about 1,000 sheep and a laboratory will be required. It is perhaps possible to undertake the work into blowfly, caseous lymphadenitis, the sexual cycle of ewes and sterility at the same place. In this connexion I would draw attention to the offer made some time ago by the Queensland Government to lend a station area under certain conditions. Since in research into sterility of ewes questions of nutrition will have to be studied at a later date as well and apparently Queensland offers the best opportunities for this, it would be advisable to re-consider the offer and make enquiries about the suitability of the station.

4. Proposed Staff.

(The Report sets out in detail the staff requirements which are summarized in the following list.)

		1 Chief of the Division.
Section I.	..	5 officers for pathological anatomy.
,, II.	..	9 officers for microbiology.
,, III.	..	4 officers for parasitology.
,, IV.	..	4 officers for bio-chemistry.
,, V.	..	3 officers for physiology.
,, VI.	..	3 officers for bio-genetics.
,, VII.	..	1 officer for Bureau.

Total 30 technical officers, 13 laboratory assistants, and 29 members of the administrative staff including 14 stockmen and agricultural men.

5. Salaries.

It will probably be the policy of the Council to bring the salaries of staff into line with those paid to officers in the other Divisions. No suggestions are therefore made, but in the appointments of officers, their special qualifications and achievements should be taken into consideration, and payments adjusted accordingly.

6. Facilities for Research.

Existing Laboratories.

The laboratories at present available in Australia for research work on problems of animal health are :—

1. *The Glenfield Research Station* in New South Wales. There is at present suitable accommodation for workers, also stables, yards and paddocks for animals. The area is 200 acres, so that there is room for extension ; the laboratory is in the country.

2. *The Veterinary Department in the University of Sydney.*—There is limited accommodation for workers, very little housing for animals and only a limited space for extension.

3. *The Veterinary Research Institute in the University of Melbourne.*—There is a certain amount of accommodation for workers, also housing for a number of animals. The Institute is in a fairly isolated locality, with a possibility of extension.

4. *The Stock Laboratory in Yeerongpilly*, near Brisbane, provides limited accommodation for workers and has quite good stabling for cattle. The laboratory is, however, mainly used for the immunization of cattle against redwater, and on this account is unsuitable for research into infectious diseases that could be transmitted to other cattle sent there for treatment, and subsequently distributed to the stations. The laboratory could be used for research into piroplasmas and other blood parasites.

5. *The Stock Laboratory in Townsville* performs a similar duty. It would be a good place as headquarters for investigations into piroplasmosis in cattle and dipping experiments.

6. South Australia has no laboratory for animal research. Some work is done at the Adelaide Hospital, but there is no accommodation for large animals.

7. Western Australia.—There are three rooms available for research, but no accommodation for large animals, and hardly enough for small animals.

8. Tasmania has no accommodation for research.

New Laboratories Required.

1. *A Central Laboratory in Canberra* is advisable. In this laboratory should be carried out most of the research work that can conveniently be taken there. It is, however, not necessary that all the problems be studied only in this place. Use could be made of Glenfield, the Veterinary Schools of the Melbourne and Sydney Universities and the Queensland laboratories. Some of the work might be undertaken in Western Australia as well. How much accommodation has to be provided in the central laboratory in Canberra can be settled only when it has been decided to what extent the organizations mentioned above will be used for research. It should be borne in mind that it will be more economical and efficient if as much as possible of the transferable research work can be carried out at the central laboratory. I have had this aspect under consideration in drawing up the requirements for that place. The subjects that could be conveniently be studied in the central laboratory are :—

> Paralysis in pigs, pleuro-pneumonia in cattle, black disease in sheep, all the helminthological work, toxic plant work, deficiency diseases, streptococcic mammitis, footrot in sheep, sterility in rams, bio-chemical problems of the healthy sheep, the study of the wool, the normal sexual cycle of sheep. Many of the subjects omitted are of no immediate importance but could be undertaken as subsidiary research.

2. *Tasmania.*—A laboratory will be required in Tasmania. It could be of a temporary nature; localities could be hired for this purpose. Investigations into twin disease could be carried out there. It should be ascertained whether the Tasmanian Government intends to put up a laboratory for its own requirements and, if such is the case, co-operation might be possible.

3. *South Australia.*—I make the suggestion that a laboratory be established at the Waite Institute with sufficient stabling for experiments for the study of the Mount Gambier haematuria in cattle. Besides, Professor Richardson is carrying out top-dressing experiments to study the carrying capacity of the area for sheep and incidentally its influence on the sheep. The assistance of a veterinary pathologist would have to be afforded from time to time to that Institute. I am making this suggestion without having discussed it with Professor Richardson. The South Australian Government should, however, be consulted as to the extent to which it is willing to provide accommodation and co-operation.

4. *Western Australia.*—The accommodation in Perth should be enlarged. It would be preferable to abandon the present place and build a laboratory with sufficient accommodation for larger animals as well, but particularly for sheep. The Government should be consulted as to the extent to which it is willing to erect accommodation for its own officers; and co-operation should be possible.

5. *Queensland.*—Should it be decided to establish a large sheep research station in Queensland, it will be necessary to provide accommodation for laboratories and for the housing of animals.

Field Laboratories Available.

A field laboratory is available in Nyngan for blowfly investigations. It contains one room. More accommodation would be required should it be decided to undertake also the lymphadenitis work and the study of the sexual cycle of the sheep.

New Field Laboratories of a Temporary Nature Required.

1. A field laboratory in Mount Gambier, South Australia, for the study of redwater. A farm may be rented for this purpose and the homestead used as a laboratory and to provide stabling for the animals. Additional sheds may be required.

2. A field laboratory in Pingelly, Western Australia, for the study of the braxy-like disease may be necessary. One or two rooms for the field officer would be sufficient.

3. A field laboratory for the study of King Island cattle disease. One or two rooms might be rented for this purpose.

4. A field laboratory in Denmark, Western Australia, for the study of the cattle disease. One or two rooms might be rented for this purpose.

5. A field laboratory for onchocerciasis in Queensland or Northern Territory. This may have to be a travelling laboratory.

(The Report then sets out in detail the accommodation in the main laboratory buildings at Canberra, including farm buildings and housing for animals.)

Fittings and Equipments.

Special fittings will be required for most of the laboratories, some of which can probably be bought ready-made. The equipment will vary with the type of laboratory. Agricultural implements and vehicles for transport of goods and animals (animal ambulance) will also have to be provided.

Probable Number of Animals required for Experiments as Outlined before.

Haematuria in cattle	20 cows
Braxy-like disease	sheep.
Paralysis in pigs	10 pigs.
Pleuro-pneumonia	20 oxen.
Caseous lymphadenitis	500 sheep.
Black disease	

Stomach worm	50 sheep.
Denmark cattle disease	10 heifers
Fatty liver	
Toxic plants	5 horses, 10 oxen, 20 sheep.
Deficiency	5 horses, 10 heifers, 20 sheep.
Contagious streptococcic mastitis ..	10 infected cows and 10 healthy cows.
Footrot in sheep	50 sheep.
Redwater (piroplasmosis)	20 young oxen.
Lung worm in sheep	50 sheep.
Onchocerciasis in cattle	
Sterility in rams	
Biochemical research of blood in sheep	10 sheep.
Development of wool	
The sexual cycle of sheep ..	200 ewes and 10 rams.
Blowfly	1000 sheep.

As no estimates have been made for some of the subjects there should be a reserve of about 100 sheep.

Distribution of the Animals.

A. Field Work.

Haematuria	10 cows—Mount Gambier. 10 cows—Adelaide.
Denmark cattle disease	10 heifers in Denmark.
Piroplasmosis	20 oxen in Queensland.
Blowfly investigations	1,000 sheep.
Caseous lymphadenitis	500 sheep.
Total number	50 cattle and 1,500 sheep.

B. Central Laboratory.

Paralysis in pigs	10 pigs.
Pleuro-pneumonia	20 oxen.
Contagious mastitis	20 cows.
Toxic plants	5 horses, 10 oxen, 20 sheep.
Deficiency	5 horses 10 heifers, 20 sheep.
Footrot in sheep	50 sheep.
Stomach worm in sheep	50 sheep.
Lung worm in sheep	50 sheep.
Biochemistry of the normal blood ..	10 sheep.
Sexual cycle of sheep	200 ewes and 10 rams.
Reserve	100 sheep.

Total Number of Animals in Central Laboratory.

Pigs, 10; Sheep, 510; Cattle, 60.

There are left out of calculation the 1,000 sheep for blow-fly investigation. I am under the impression that this number is already used in experiments in Nyngan. Included are 500 sheep required for lymphadenitis. It is perhaps possible that the flock in Nyngan may be used as well, if it is not decided to have a special station or farm for this purpose.

V.—THE POLICY OF THE DIVISION OF ANIMAL HEALTH.

It is evident that the Division of Animal Health of the Council cannot be a watertight unit. To attempt to make it so would be fatal. There should be co-operation with the Departments of Agriculture of all the States, with the Federal Department of Health (Quarantine Division) and the Veterinary Research Institutes of the two Universities. The assistance of the Stock Departments is essential; their officers are required to make first-hand observations about the prevalence of certain diseases, for the collections of pathological specimens, parasites, and toxic plants. They should be the outposts for research, and their observations should be brought to the notice of the Research Division. Co-operation is also necessary with other branches of the various Agricultural Departments, the botanists and agrostologists, who should bring their observations concerning animal health to the Division. There should under all conditions be a hearty understanding with the State officers engaged in research work. At present, every State has at least one such officer. They are usually occupied with the routine diagnostic work of the Stock Department, but, should their time permit, they should be encouraged to do some research work, and assistance to such should be given. Co-operation with the veterinary schools should also be established. There are certain aspects in the animal health that might profitably be studied at such places. These relate more particularly to the study of normal conditions of different classes of animals. Also, the abattoirs should be made use of and the different governing bodies should be advised to give facilities for research work, should it be found necessary to undertake such in an abattoir. The Chief of the Council's Division should not pretend to control any of the independent organizations that are willing to co-operate. There should be consultation about the problems to be studied and a programme drawn up. Once it has been approved, it should be under the supervision of the officer in charge of the State institution. Progress reports should be supplied and discussed. A final decision for the continuance of the work will, however, remain with the Chief of the Animal Health Division. Hearty co-operation with the other Divisions of the Council will be essential. There are several problems in which the entomologist is interested as well, viz., buffalo fly, blowfly, onchocerciasis; and the programme for research should be determined after consultation with him. It is even possible that the same material could be used by the two Divisions. Similarly, co-operation with the economic botanist is necessary. Problems of toxic plants and questions of research in food plants are of interest to both. Also, intimate touch should be maintained with the Division of Animal Nutrition; here particularly are numerous points of contact.

A further line of policy should be not to interfere with the duties of the State officers, viz., extension work and administrative work. The Division should not offer advice to farmers, and care should be taken that it is not simply used as an office for information. There has been an impression amongst pastoralists that to this Division, or Bureau, as it has been frequently called, requests for assistance can be sent. Correspondence with pastoralists and farmers should be limited to inquiries about facilities for research, occurrence of disease, and supply of material, provided that such is not forthcoming through the officers of the Stock Departments. Furthermore, it should not become the business of the Division to do routine work for the purpose of diagnosis of disease. The various pathologists of the Stock Departments do this work; should they require information it should be willingly given. There should also be no tendency to develop the production of serums or vaccines, should such result from the investigations. This should be the function of a different institute altogether, probably the Commonwealth Serum Laboratory. The Division should publish its reports in the journals of the Council or in special bulletins or pamphlets issued by it. Contact should be established with institutes in all parts of the world by the exchange of publications, and a special library should be built up.

VI.—THE EMPIRE OUTLOOK OF THE SCHEME.

The Conference of research workers in Agriculture held in October, 1927, has opened up a wider outlook in all scientific research work within the British Empire. Problems are no longer considered to interest only one part of the Empire, but the Empire as a whole. This is the right outlook, and such a conception should stimulate all enterprises. The scheme as put forth by myself has an Empire outlook. The problems referred to interest most parts of the Empire, but particularly the old country. Great Britain has established the Empire Marketing Board to assist the development of all Empire resources. Australia can help in this develpoment. Problems in nutrition and deficiency are met with in all countries, but are most particularly found in arid and semi-arid regions, which occur in Australia and Africa; but Australia offers special opportunities for the study of them, and full advantage should be taken of this fact. Most of the animal diseases are present in all other countries, and some even in Great Britain, but facilities in Australia for their solution are greater than there, the animals necessary for research work being cheaper. Accordingly, the research work will be more economical. The Council should bring this to the notice of the Empire Marketing Board. The London Conference adopted a resolution that the facilities offered by Onderstepoort should be taken advantage of as one of the research stations. Onderstepoort studies mainly the special problems of Africa, and in this respect has a particular advantage. The problems of Australia are to some extent identical; Australia develops, however, new problems in animal health associated with intensive agriculture, and this will appear anywhere where the extensive exploitation of animals goes over into an intensive one. These could be best studied in Australia. It would certainly be advisable that the Division I propose that Australia should establish should also form a link in the Research Station chain of the Empire.

VII.—THE SUPPLY OF RESEARCH OFFICERS (TRAINING).

Australia has had in the past two Veterinary Schools for the training of veterinary surgeons—one in Sydney and one in Melbourne. It is likely that the latter will be discontinued as a teaching institution. It is to these schools that the Council has to look for its further supply of research officers. The main object of the schools at present is to train veterinary practitioners. A certain amount of training in research work is undertaken. It is evident that no fully-trained officer can be obtained from them. It is therefore the duty of the Council to make provision for post-graduate training. This can be obtained in overseas institutes—in England, on the Continent of Europe, in America, and in Africa. It should be the policy to send every officer at least once during his career to one of the overseas institutes. The institution of the so-called sabbatical year might meet this proposition. The main laboratory should also make provision for post-graduate work, and laboratories should be provided for this purpose in the different sections so that special work could be carried out. It is even suggested that the Division should organize from time to time post-graduate courses in special subjects, which could be attended by graduates who wish to specialize in research work. Likewise the laboratories of the Division should be open to overseas workers. A system for exchange of students or research workers should be contemplated. It would be advisable to encourage research workers to learn foreign languages, particularly German and French, to enable them to read publications in these languages. The system of fortnightly or monthly conferences of all the research workers, at which their own particular research work would be discussed and foreign publications be brought to their notice, should be initiated. In this way a close touch between the various workers would be maintained, efficiency kept up to the highest mark, and interest stimulated in each other's work.

VIII.—RECOMMENDATIONS.

The scheme as outlined by me would appear to be one of considerable magnitude. Considering the wide range and the diversity of subjects that fall into the province of animal health, the proposed organization is, in my opinion, of moderate circumference. The Institute at Onderstepoort, South Africa, which was founded and organized by me, did not deal with all the aspects of animal health, as I propose should be done in Australia. It dealt almost exclusively with disease. It is true that the activities were somewhat different, inasmuch as they included services to the farmers by correspondence, demonstration trains, the supply of serums, vaccines, and drugs, testing dip materials, routine diagnosis, etc. There was attached to the Institute a Veterinary Faculty. It was carried on almost as a sideline to the research work. All these activities were a gradual development resulting from the research portion of the staff. Onderstepoort had the advantage of plenty of cheap labour, and much of the routine work was done by trained lay assistants, leaving to the qualified staff the supervision and ample time for research. In comparing thus the two organizations, Onderstepoort was a much bigger one for a limited number of subjects; yet the stock population of South Africa is much smaller than that of Australia. There are 30,000,000 sheep and 9,000,000 head of cattle in the former to 100,000,000 sheep and 22,000,000 cattle in the latter. The Institute at Onderstepoort was the result of a gradual development, beginning very moderately and finishing magnificently. It could not be foreseen to what the first enterprise would lead, and its evolution was subsequently a natural one. Having had all that experience, I have applied it to the problems of Australia and have made a forecast of what I see will be the institution of the Commonwealth when it is allowed a natural growth.

Not the whole scheme need be carried out at once, but provision should be made from the very beginning so that it can develop in time. This applies in the first instance to the site of the main laboratory in Canberra. I have estimated an area of more than 500 acres, including agricultural lands. I do not think that less will be sufficient. There are experiments that will have to be carried out on the pasture lands, keeping animals under as natural conditions as possible. There are grazing lands required to reduce the costs of feeding, paddocks for observations, and yards for handling stock.

The laboratory should be built into this area, or as near as possible, and certainly near the laboratory ought to be the stables and pens for experimental animals. Such animals must be under constant supervision, and access should be made easy. If any extra effort is required to visit the animals, it is often postponed or left over and material is wasted. I have proposed the building of one main block for administration; it should be independent from all others. There should be one building for bacteriological, pathological, and parasitological work; one building for biochemistry and physiology and genetics. The operation hall and the *post-mortem* building should be so erected that all have easy access to it. The stables, pens, sheds, and paddocks should be so arranged that the animals can be fed in the quickest and most economical manner. All the other buildings should be placed in harmony with the site. Future expansion must be kept in mind all the time.

It may be thought advisable to delay the building of the main laboratory in Canberra, making use of such places as Glenfield and the University Veterinary Faculties of Sydney and Melbourne. Glenfield certainly could be developed, and would have sufficient area if a more restricted outlook of research activities were planned. There is little room for expansion at the Universities, and activities will therefore always be restricted. Whilst the establishment in Canberra may be delayed, that of local laboratories in Tasmania, South Australia, and Western Australia should not. Such laboratories will probably also serve for the local requirements of the respective Stock Departments, and the State Governments should be consulted for co-operation. There should be no delay in extending the research undertaken in Mount Gambier with haematuria in cattle, and with the braxy-like disease in Western Australia, which can only be successfully dealt with in the way indicated before.

My principal recommendation is the early appointment of a Director or Chief of Division, who has in his career been associated with organization of research work, is accustomed to a wide outlook, and has the courage to shoulder responsibilities. I do not see any other efficient way to carry out the research work of the Council. It is possible to restrict the scope of the investigations and to proceed in a different manner to that proposed by myself. I admit it can be done, but it means playing with research and in the long run it will be wasteful. My experience has taught me that the more boldly a problem is attacked the sooner it yields to the efforts. There will be a period of transition until the Chief of the Division has been appointed. This period should be utilized to enlarge the work in the sub-stations, as indicated, and to come to arrangements with the State Governments mentioned for the erection of suitable laboratories. The work at the other stations should be carried out as hitherto.

My main advice to the Council is to take a wide outlook into the research of animal health. Australia's main industries are those of primary production; they are based on the health of animals. Animal health is national wealth.

The alternative organization would be one of decentralization. There would be no central laboratory and no Director with staff. The work would have to be done in the already existing laboratories and in those the building of which is recommended in the different States and localities as outlined before. The work could be split up amongst the different State pathologists, who for the purpose of this scheme would become officers seconded to the Council. The officers engaged on specific problems would work under their direction and report progress through them. The distribution of the problems would be determined by a meeting of the officers concerned, who at the same time could draw up a plan of research and estimate of costs. This decentralization would mean extension of accommodation in the laboratories already existing for the problems allotted to them, wherever existing facilities are not sufficient.

In laboratories like those of New South Wales, Victoria, and Queensland, research in major infectious diseases could be undertaken, whilst the study of the normal health as well as minor diseases could form a suitable subject for the University Veterinary Faculties. The study of the sexual cycle of the sheep and lymphadenitis could consistently be linked up with that already undertaken in Nyngan into blowfly of sheep.

This scheme would obviate the building of a central station; there would not be any administrative staff, and accordingly there would be reduction in expenditure.

This proposition has its disadvantages; the main one lies in the decentralization itself. There would not be a controlling influence, and most likely there would be a waste of material. The central laboratory would have all the facilities for research, and no multiplication of apparatus, etc., would be required. A central store would be an economic advantage. A great disadvantage would be the lack of intercourse between the different officers, and the isolation would lead to a number of other disabilities. Strong-minded, individualistically disposed workers would hardly suffer, and in their case decentralization would be an advantage. In the case of most workers, particularly younger ones, it would be the reverse.

IX.—ACKNOWLEDGMENTS.

I wish to take this opportunity to express my deepest gratitude to all who have assisted me in my investigations: to the Council in the first instance, and particularly to Dr. A. C. D. Rivett, Chief Executive Officer, and his staff, who constantly placed their services at my disposal; to the Chairmen of the various State Committees and their Secretaries; to the Chiefs of the various Stock and Agricultural Departments and their officers, who gave me willingly the benefit of their experience; to the Directors of the Veterinary Schools, Superintendents of Abattoirs, and their Inspectors; and last, but by no means least, to the Pastoralists and Graziers' Associations, and the pastoralists and farmers themselves, whose hospitality I received, and whose practical outlook was a guide and often an inspiration to me.

MEMORANDUM ON RESEARCH IN NUTRITION IN AUSTRALIA.

BY

DR. J. B. ORR (DIRECTOR, ROWETT RESEARCH INSTITUTE, ABERDEEN).

1. General.

The chief object of the visit to Australia was to exchange views with research workers there on investigations in animal nutrition in which they and similar workers in Britain were mutually interested. The results of discussions at interviews and informal meetings on a wide range of nutritional and allied problems cannot be set forth in a detailed formal report. It may be stated, however, that in my discussions with these workers I obtained information, new ideas, and fresh points of view, which could not have been gathered from published papers or even by correspondence. Some of this information will be of real value, especially in connexion with Empire investigations in which the Rowett Institute is co-operating through the Research Grants Committee of the Empire Marketing Board. On the other hand, Australian workers appear to be keenly interested in the information I was able to give on the methods of attack and on the results of work on problems of nutrition in Britain and in other parts of the Empire. As a result of this visit, which established personal contact with workers in Australia, there is likely to be a continuous exchange of information by correspondence which will be of great mutual value.

In addition to meeting the research workers in the different States, I had the privilege of attending some of the meetings of the Council for Scientific and Industrial Research and hearing discussions on schemes of research on nutrition and allied subjects. These discussions were most informative, especially with regard to the organization of research on a scale to meet the economic need of the Commonwealth.

From the results of the visit, I am convinced that the meeting together of senior workers and those concerned with the general direction and organization of research in animal nutrition, is of even greater importance than the exchange of junior workers, and the lead which has been taken by Australia in sending senior officials to Britain and in inviting British workers to visit Australia is likely to be followed with great profit by other Governments.

Australia is so large and contains within itself so many different conditions of soil and climate, that a seven weeks' visit is too short to enable one to get first-hand information on all the various problems of animal husbandry in the Commonwealth. The following notes should, therefore, be regarded as merely the impressions of a visitor who has been fortunate enough to see a small part of the continent and to discuss problems of animal husbandry with stock owners and officials who are engaged either in the administration, or the actual carrying out, of research on the subject.

2. Economic Conditions.

The total exports of Australia (1926–27) amounted to approximately £145,000,000. Of this total, animal products represent £79,000,000, i.e., rather more than half of the total exports. Animal husbandry is, therefore, the most important industry in Australia.

Owing to the vast extent of land and the sparse agricultural population, the stock farming which yields these products is carried on for the most part on an extensive, rather than an intensive, basis. Permanent natural pasture forms the sole raw material for the greater part of what is produced. The feeding of concentrates to increase production is not generally practised, and on the greater part of the pasture areas the land has not been cultivated or treated with fertilizers to increase the feeding value of the pasture. Hence the number of animals kept per acre, and, in the case of cattle, the production per animal, is considerably less than in countries where more intensive methods are practised.

But there are large tracts of grazing land where the rate of production could be rapidly increased. Ignoring, for the meantime, economic difficulties, it may be stated that the yield of animal products in Australia available for export could be doubled within a few years. As a matter of fact, the change over from extensive methods to more intensive methods, with increased production per acre and per animal, is taking place at the present time, especially in the southern part of the continent, and the question at issue is the extent to which science can yield information which will accelerate what is a natural development.

It may be assumed that production can be increased and that scientific research may accelerate the rate of increase. The question to be considered is the lines along which the available research effort should be directed to secure the maximum economic results in the immediate future. But the economic results depend upon the market for the increased products. Hence marketing must be considered in outlining Commonwealth schemes of research.

One of the products that deserves special attention in this respect is wool. At the present time, wool forms more than two-fifths of the total exports of Australia, and a sudden slump in the price of wool would seriously affect the Commonwealth. But in undeveloped parts of the north, east and south of Africa, there are large tracts of grazing lands with a pasture and a climate closely similar to parts of Australia where the best wool is being produced. In these parts of Africa, attempts are being made to develop the sheep industry with the same breed of sheep which has contributed so largely to the prosperity of Australia. Unless there be an increased consumption of wool, an increase in production in Australia, occurring simultaneously with the production of considerable amounts of similar wool from other parts of the world, will cause a fall in price which will make the wool crop of less value to the Commonwealth.

If it be thought that there is any danger of the world's consumption of wool lagging behind production, it is desirable to work towards a broadening of the basis of the live-stock industry by increasing the production of mutton and developing the cattle, dairy, pig, and poultry industries. Further, apart from the question of markets, the developments of these branches of the live-stock industry will lead to the better exploitation of the land and to closer settlement.

Australia has vast tracts of land where the soil and the climate are eminently suitable for these branches of stock farming. Thus, Queensland has ample natural foodstuffs for an enormous increase in cattle, and it is believed, at least by some economists, that while there is likely to be an increase in the consumption of meat accompanying a rise in the standard of living throughout the world, the present sources of the meat supply are unlikely to yield an increasing amount available for export. In the same way, the consumption of milk throughout the world is likely to increase and there are large areas of land, especially in the south of Queensland and in New South Wales, eminently suitable for dairy farming. In these districts, the present milk production is only a fraction of the possible output.

There is a large market in Britain for these products, but Australia's exports are very small in comparison with the amounts absorbed in this market. This is shown by the following table* which gives the imports into Great Britain (for 1927) and the exports from Australia of mutton and lamb and the products of the cattle, dairy, pig, and poultry industries.

Industry.	Imports into Great Britain.	Exports from Australia.	
		To Great Britain.	Total.
	£	£	£
Cattle	57,183,335	1,132,271	2,697,412
Dairy	66,793,655	4,588,914	6,661,890
Pig	48,941,557	54,368	170,047
Poultry	22,306,647	231,843	265,266
Mutton and Lamb	17,932,906	1,942,956	2,057,607
Total	213,158,100	7,950,352	11,852,222

A market for live-stock products other than wool is obviously available, and Australia, with large tracts of suitable land only partially developed and a climate admirably suited for stock, has a capacity for production far greater than that of certain foreign countries which are at present the chief exporters to the British market.

If the above considerations be correct, it seems desirable, for both economic and political reasons, not to concentrate too exclusively on wool. Every effort should be made to develop them along intensive lines which will tend to give both low cost of production and standardised high quality products which find the readiest market and best price.

* The writer is indebted to F. L. McDougall, Esq., C.M.G., of Australia House, London, for the above figures.

3. Schemes of Research Depend on Nature of Development.

There are many lines of investigation in connexion with these branches of animal husbandry which could be profitably undertaken if sufficient men and money were available. But in Australia, as elsewhere, the number of competent research workers is limited, and it is desirable to concentrate effort along those lines which are likely to yield the maximum economic result in the immediate future. Hence, before outlining any new scheme of research in nutrition, the economic position should be reviewed from the Commonwealth point of view to determine the present state of the industry, the branches of it which it will be most profitable to develop, and the difficulties that are likely to be met with in the course of its development. In making this survey, the nutritional experts would need to work in close co-operation with leading stock owners and with veterinarians and other officials who can give information bearing on the industry. Such a survey would reveal the relative importance and urgency of nutritional problems and enable schemes of research to be outlined for definite economic ends.

It can be predicted that whatever the results of such an inquiry, it would be found that there was need for investigation on such subjects as the availability and use of concentrates for feeding for intensive production, the utilization of by-products from creameries, slaughter-houses, bacon factories and fisheries, and the handling and transporting of milk, meat and bacon. But the relative amount of effort which would be devoted to these and other lines would need to be decided in the light of the information brought out by the suggested economic survey.

There is a great volume of work already being carried out throughout the world on problems of the same nature as those with which Australia is faced, or is likely to be faced, as the live-stock industry is developed, and it would probably be found that in most cases when all the available information had been assembled, the kind of work needed in Australia for the first few years, at least, would be practical experimentation with the object of applying existing scientific knowledge to local conditions. It will also probably be found possible to carry out a good deal of this practical work at existing institutions such as agricultural colleges.

The above considerations are put forward because it is believed that the great need of Australia in connexion with animal husbandry in its present state of development is not so much research in nutrition *per se* as the application of existing knowledge to pressing practical problems, and that the objective of this practical experimental work needs to be adjusted, and if necessary will need to be periodically re-adjusted, according to the changing nature of these problems.

4. Investigations of Immediate Practical Importance Irrespective of Direction of Further Development.

Although the development of research in nutrition would need to be considered in the light of the development of the live-stock industry, there are certain basal problems which are independent of the state of development of the industry and which are common to all the grazing areas in Australia. The most important of these are in connexion with pastures which are the chief raw material for animal products.

A. Research in Connexion with Pastures.

There are large tracts of grazing lands in Australia where the pastures are deficient in phosphates. Deficiency of other minerals, e.g., lime, iodine, sodium, or chlorine, are also believed to occur in certain areas. These deficiencies affect the feeding value of the pasture.

Deficiencies become accentuated with continued grazing when there is no return to the soil of the nutrients carried off in the wool, milk, or carcasses of the animals. A striking example of this process of deterioration occurs in the south coastal area of New South Wales. In the neighbourhood of Mowra, where thirty years ago cheese-making flourished, the milk yield from dairy cows has decreased so much that at the present time on some farms it does not exceed 200 gallons of milk per cow per annum, and the cows have the typical appearance of animals suffering from phosphorus starvation. I am informed that the same conditions are beginning to appear in the north coastal area, where dairy farming began later than in the south.

The phosphorus requirements of the sheep are much less than those of the milking cow, so that signs of deterioration would be less marked and be later in appearing in the case of sheep than in dairy cows. There are, however, indications that the same deterioration is occurring on some sheep stations.

In addition to this deterioration due to the removal of nutrients, there are areas where, in times of scarcity of pasture, the existing herbage is literally eaten out. In some districts with low rainfall, land which at one time had a covering of vegetation of considerable value for feeding is tending to become barren.

There are two methods of dealing with this process of deterioration in pastures, viz., the application of fertilizers to the soil, and the feeding direct to the grazing animal substances such as salt licks, containing the nutrients deficient in the pasture.

Pasture Improvement.—Application of fertilizers in the form of top dressings with phosphates is commonly practised in the southern part of the Continent. A good deal of further research is, however, required with regard both to phosphates and other fertilizers. Practical experimental work, with the object of testing and applying existing knowledge, is being carried out on sound lines at the Waite Agricultural Research Institute. Original research is also being done, and the investigations on the effect of fertilizers on physiological processes of plant growth on soils with low moisture content is already yielding results which, if confirmed, will be of great economic importance, not only to Australia, but to other parts of the Empire in which there are pastoral areas with low rainfall.

It was primarily in connexion with this original research that the grant from the Empire Marketing Board was made to this Institute. In view of the suitability of the climate, the excellent facilities for work, and the promising way in which the research is developing, the Waite Institute should be regarded as the centre for the whole Empire for research work on pasture problems related to scarcity of soil moisture.

Experimental work in other countries, with similar conditions, e.g., parts of Africa and Asia Minor, should be based on the researches carried out in Australia. The organizations now being devised for Empire co-operation will provide means for establishing the necessary liaison.

This work on the application of fertilizers has a direct bearing on the work of the plant breeders, as it is known that a change in the composition of the soil is followed by a change in the flora. It also has a bearing on the work of veterinarians because changes in the pasture affect the health of the grazing animal. It is desirable, therefore, that the plant breeders and veterinarians should be kept in close touch with this work. An *ad hoc* committee containing plant breeders, veterinarians, and pastoralists, in addition to soil chemists, should be formed to consider the whole question of pasture improvement and to secure the necessary co-operation between the different groups of scientists and also the immediate exploitation of results obtained.

Salt Licks.—The administration of substances such as salt licks calculated to supply nutrients lacking in the pasture has become common practice in Australia. There are a number of companies manufacturing salt licks, and there is no doubt that in most cases these have a beneficial effect which is out of all proportion to the relatively small cost of the material used. The value of a salt lick or mineral mixture, however, depends upon the extent to which it supplies exactly what is lacking in the pasture, and the nature and amount of what is lacking varies in different areas and at different seasons. But salt licks being put on the market are, on the whole, merely empirical concoctions supposed to supply the deficiencies in all areas and in all seasons. If exact information were available with regard to the deficiencies in different areas and at different seasons, it would be possible to compound licks which would approximately supply the deficiencies and would, therefore, yield a much better return at less cost.

There has already been a certain amount of valuable work done in Australia showing the nature of deficiencies in pastures in some areas, and work of a fundamental nature has been commenced at Adelaide University* to determine the composition of certain species of pasture plants with regard both to mineral and amino-acid content. This latter work, however, though doubtless of great ultimate value and likely later to be the basis of practical work, may not yield practical results in the immediate future.

It is suggested that a more rapid survey of various representative areas should be done to determine the gross deficiencies, and when the nature of the deficiencies has been determined, feeding experiments with sheep and dairy cattle should be carried out on the stations and arms to determine the effect of feeding, in the form of salt licks or otherwise, the nutrients found to be deficient in the pastures.

In Brisbane, there are excellent chemical laboratories, and the Chief Chemist† has first-hand experience of this kind of work. In New South Wales there is an active, energetic staff of veterinarians who have

* A reference to the co-operative activities of the Division of Animal Nutrition of the Council.
† Of the State Department of Agriculture and Stock.

experience on the clinical aspect of this work, and the Glenfield Veterinary Research Station and the Veterinary Department of Sydney University have the necessary accommodation and staff for carrying out whatever veterinary work is required.

If four or five junior whole-time chemists and field workers with experience in carrying out feeding experiments were appointed to work in co-operation with, and under the technical guidance of, the State and University officials, it would be possible to form a team which would enable an extensive investigation to be carried out within three or four years.

In Western Australia, I was informed that there is an area where gross malnutrition occurs, due, it is believed, to deficiency of calcium in the pastures, and there are some workers there, including a junior member of the staff who has had a special interest in work of this kind and is keen to undertake an investigation in this area. The carrying out of this relatively small investigation in Western Australia should be encouraged, and the general methods used there should be in conformity with those employed in Queensland and New South Wales, so that the results would be comparable.

These temporary investigations, the larger one based jointly on Brisbane and Sydney, and the smaller one based on Perth, would, of course, be linked up with the more fundamental and permanent work being carried out at Adelaide. The whole of the work would be linked up through the Commonwealth organization—the Council for Scientific and Industrial Research.

This is work in which some of the leading pastoralists are so interested that they would provide sheep and other facilities for experiments on the stations. By taking advantage of these and of the existing laboratory facilities, no capital expenditure would be necessary. The whole time workers would be juniors, who would be appointed as temporary workers for the investigation, so that there would be neither capital expenditure nor permanent recurrent commitments.

If this investigation be undertaken, it should be carried out under the supervision of a special committee, including chemists, veterinarians and pastoralists. This committee would bring to bear on the problem all the available information already in existence from the chemical, veterinarian and practical points of view, and would ensure that the investigation was kept continually directed towards the main practical objective.

There is a Pastoral Sub-Committee of the Civil Research Committee of the United Kingdom which for the past three years has been accumulating information on this subject, and has at its disposal data with regard to similar work in various parts of the Empire. The information which this Committee is accumulating would be of value for the Australian work and could be obtained through the Council for Scientific and Industrial Research.

It is of interest to refer here to a special piece of work on the lines indicated above, which has already been done in the case of one station in Queensland. I was informed by the Chief Government Chemist there that the feeding of a proper salt lick which was compounded on the results on the analysis of pasture, has resulted in a remarkable improvement in the sheep and a marked increased carrying capacity of the station. I was not able personally to visit this station, but the results claimed are on the same general lines as those being obtained in some other parts of the Empire where work of a similar nature is being done in areas where there are marked deficiencies in the pastures.

Iodine and Goitre.—In addition to nutrients which are required in relatively large amounts, e.g. proteins, calcium, phosphorus, sodium, chlorine and potash, other substances such as manganese and iodine, though required only in traces, have still important functions in connexion with both the growth of pasture and the nutrition of the grazing animal. Work on manganese in relation to plant growth is being carried out at the Waite Institute, and iodine in relation to goitre is being studied at Adelaide University. It is probable that the latter problem is of considerable economic importance, as deficiency of iodine is an important factor in the health and disease of sheep. The work being done on this subject is excellent and it should be pushed on as rapidly as possible.

Work on somewhat similar lines is being done in various parts of the Empire and the Nutrition Committee of the Medical Research Council in London is carrying out a rapid survey in goitre areas in England, and at the same time is assembling all the available information bearing on the subject including information about work being done in different parts of the Empire. It is suggested that liaison should be established between the Australian work and this Committee in London. This would involve no expenditure, and might prove of considerable mutual advantage.

Wool.—It has been observed by pastoralists that the improvement of pastures by top-dressing with phosphates improves the carrying capacity of the pasture and the nutrition of the sheep, but this is accompanied by deterioration in the quality of the wool. It has not been definitely proved that this improvement in the nutrition of the sheep must necessarily be accompanied by deterioration in the quality of the wool. It is probable that the quality of the wool depends upon certain specific dietary factors as well as on the general condition of the health of the sheep. The question, however, is obviously of economic importance and is involved in the whole question of pasture improvement. There appears to be need for experimental work bearing directly on the effect of the feed on the quality of the wool.

Research of a fundamental nature on the composition of the wool is being undertaken at Adelaide University. Under the same scheme, tests are being carried out at the Waite Institute on the effect on the wool of feeding a protein constituent to the sheep. In addition to this research work, there is need for a series of practical feeding experiments to determine the effect of different diets on the weight and quality of fleece, with the object of throwing some light on the dietary factors on which the rate of growth and quality of the wool depend.

On account of the great practical importance of this work and its relation to the whole question of pasture improvement, it would appear desirable to form a committee including nutritionalists and pastoralists with a knowledge of both breeds of sheep and quality of wool. Further, it would be very desirable for this work on the quality of wool to be linked up with the work of the British Research Association for the Woollen and Worsted Industries at Leeds.

Feeding experiments are at present being carried out in Scotland to test the effect of certain nutrients on the growth of wool, but there is not likely to be the same volume of work carried out there as in Australia. It would be of advantage to the work in Scotland if the workers there were kept informed of the progress of the work in Australia. Indeed, it might be found desirable to regard Australia as the centre for the Empire for research on the problems in connexion with the production of wool.

Conservation of Pasture.—It is known that the nutritive value of pasture is at the maximum at a certain period of growth, after which it deteriorates. Under normal conditions, this seasonal wave of pastoral wealth comes every year, but only a fraction of the material is eaten by the animals when it is at its maximum value. There is need for a cheap method of conserving it at this stage and putting it into a form in which it would be easily stored and cheaply transported. This problem is under investigation at Cambridge University. There is, therefore, no need for Australia in the meantime to expend effort on this problem. But as a conservation of fodder is probably of more importance to Australia than to any other part of the Empire, especially in view of the development of the growing of forage in irrigation areas, the closest contact should be maintained with the work at Cambridge with the idea of the results being tested out in Australia so soon as it appears evident that they are likely to be practicable. There is no necessity to discuss this important question further, as the Empire Marketing Board has recently published a monograph dealing with this subject: "Grass and Fodder Crop Conservation in Transportable Form," by A. N. Duckham, Rowett Research Institute, Aberdeen.

Drought.—The feeding problems caused by drought are interlocked with other problems such as those of transport and storage. Hence an investigation from the purely nutritional point of view would be too limited in scope to yield the desired practical results. The problem needs to be studied in all its different aspects by a committee which would include pastoralists, economists, transport experts, veterinarians and nutritionalists. The main contribution of the nutritionalist to the solution of the problem would be information on the food requirements of sheep, the best kind of concentrates to use during drought, and the best method of conserving food grown within the drought areas in good years for use during periods of scarcity.

Some of the research work referred to above will indirectly make contributions to the partial solution of the drought problem. Thus, the results of some of the work being done at the Waite Institute suggest that it may be possible to make pastures more resistant to drought. If it be found economically possible to apply these results, evil effects of drought would tend to be deferred.

As information on the improvement of pasture accumulates, it may be found profitable to lay down small areas for the intensive production of pasture which could be stored so that there would always be a supply on hand, the excess beyond a fixed amount which would be regarded as a reserve for drought, being used for the feeding of a "floating" stock, such as fat lambs, which could be sold off in the beginning of a time of scarcity.

If, as seems possible, work on the conservation of pasture results in the elaboration of a cheap method of treating young pasture or forage crops like lucerne, so that the material can be easily stored and transported and still retain practically its whole nutritive value, the cost of supplying food from the irrigation areas would be decreased and the feasibility of conserving food grown within the drought areas during good years would be increased.

As intensive methods of stock farming develop in the districts adjoining drought areas, there will be an increasing amount of both pastures and concentrated foodstuffs in these districts, which will consequently be able to absorb some of the stock from the drought areas. It is probable that, in the future, the adjoining areas with the more reliable rainfall will become more and more efficient as a buffer which will minimize the effect of drought and give more time for the adjustment of the live stock to the available food. Indeed, as the stock industry develops, the effects of drought will tend to become less, because all over, the ratio of food to animals will be increased and even in periods of drought the ratio will not fall so low as it does under the present system in which, on the drought-stricken and adjoining areas, unimproved pasture form almost the whole of the food supply. While, therefore, there is a great need for a direct frontal attack on the drought problem, attention should also be given to those indirect measures which will tend to minimize the terrible losses which occur periodically.

B. Lines of Investigation other than those connected with Pastures.

As pasture is at present the main source of wealth of the Commonwealth, and as the results of recent research throughout the world give reason to believe that the pasture products available for export could be rapidly increased within the next few years, it is a sound policy to give priority to investigations of the nature of those outlined above. The investigations have reference especially to sheep, but as a matter of fact the improvement of pastures can be regarded as fundamental for the development of the beef and dairy industry, and also to a certain extent to the pig industry.

There are, of course, investigations required in connexion with dairying, beef production, pigs and poultry. It is doubtful, however, whether any single individual has all the necessary information which would enable him to determine what are the most profitable lines of research in connexion with these. In discriminating between a multiplicity of investigations which might all yield interesting results, a number of factors other than those directly related to nutrition must be taken into consideration. Thus, for example, account must be taken of the probable effects of the development of irrigation areas. The supply of foodstuffs from these will affect what is one of the most important problems in connexion with the development of the live-stock industry, i.e., the supply and use of concentrates. Then again, developments in connexion with the elimination of disease, especially insect-borne disease in Queensland, need to be taken into account in considering the research work which would be most profitable in the beef industry. Factors such as these must be considered in determining what lines of investigation are most likely to yield information which can be applied to economic ends. It is for this reason that it has already been suggested that a group of economists, pastoralists, veterinarians and nutritionalists should survey the whole field of animal husbandry before new schemes of research on these subjects are undertaken. The pasture problems, on the other hand, are on the whole, fairly straightforward and definite, and work on these can be extended and intensified with confidence that there is a likelihood of obtaining economic results out of all proportion to the costs of the investigation.

5. Organization of Research.

Although it involves some repetition of what has been already said, the benefits of co-operation in studying the main practical problems of animal husbandry may be specifically referred to here. As has been indicated throughout this memorandum, all the lines of investigation discussed are already, to some extent, receiving attention from research workers in Australia. Any suggestions made are merely for the extension of existing work, especially along the lines most likely to yield information of economic value at the earliest possible date. To secure this practical result with the nimimum of expenditure, it is necessary, on account of the nature of the problems, to arrange for co-operation between different institutions, between the officials of different States, and also between the scientists who have the technical knowledge and the stock owners who have the practical knowledge and the economic outlook. By such co-operation, it will be possible to take fuller advantage of the existing facilities for research, irrespective of what State they may be in, and, what is equally important, to get the benefit of existing knowledge, much of which and indeed in some cases the most valuable part of which, has not been committed to the literature on the subject and cannot be obtained except in discussions between men viewing the problem from different aspects.

It is recognized that there are certain rules and regulations and agreements defining the sphere of activity of State and Commonwealth officials. These regulations are of little importance compared with the economic development of this great continent. From the conversations which the writer has had with research workers, officials, and stock owners in Australia, he is convinced that when they get settled down in groups to study the big economic and scientific problems, there will be so much interest developed in connexion with the work which affects Australia as a whole that less and less attention will be paid to artificial political divisions either of the continent or of research activity. This method of making the big economic problem, instead of the political or other organization, the centre for grouping research workers has been developed in Britain during the last few years, and has been an invaluable stimulus to research.

In various branches of its activity, the Council for Scientific and Industrial Research in Australia is already moving along the lines indicated. In the case of animal husbandry there may be difficulty in getting the necessary team work evolved, on account of the fact that the subject is so wide and involves so many different branches of science, and so many spheres of industrial activity. The Council will need the assistance and loyal support of all the research workers and officials interested in this industry.

This memorandum cannot be concluded without paying a tribute to the valuable research work which has been done in Australia in the past. Individual pieces of work by Australians, especially on the mineral content of pastures and on the influence of nutrition on disease, have not yet received, even within Australia, the attention which their value warrants. The results of some of that work have been applied successfully in other parts of the Empire and have also stimulated further research in mineral metabolism. The present workers in Australia are as competent as their predecessors, and with the wider organization created by the Council for Scientific and Industrial Research and the increasing amount of funds made available, they will have a powerful influence in developing animal husbandry in the Commonwealth of Australia, which in the opinion of the writer is destined to become the world's greatest stock farm.

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COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

THE

TASMANIAN GRASS GRUB

(*Oncopera intricata* Walker)

A Preliminary Report on its Life History, and Methods of Control

By

GERALD F. HILL

MELBOURNE 1929

By Authority:
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COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

THE

TASMANIAN GRASS

COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH.
BITTER PIT OF APPLES IN AUSTRALIA—BULLETIN 41.

ERRATA.

Page 24 Description of figure, For Camera lucida x 220 read Camera lucida x 150.
„ 31 Line 9, for (Fig. 49, p. 485) read (49, p. 485).
„ 35 Description of figure. For Camera lucida x 63 read Camera lucida x 45.
„ 38 Line 7, for Barker (68) read Barker (see p. 82).
„ 43 Line 6, for 54, 5 read 38, 15. Line 15, for 38, 15 read 54, 5.
„ 44 In table, for 289 apples read 298 apples; for 258 apples read 158 apples; for 22/2/27 read 23/2/27.
„ 49 Under Fifth Picking, for Figs. 28 and 29 read Figs. 25 and 26.
„ 52 In table, for 13.2.28 read 13.3.28.
„ 54 Line 27, for (43.68) read (see pages 45.82).
„ 61 Table 7, 3rd line, for 20th April read 23rd April.
„ 64 Line 4, for "detailed" read "detached".
„ 68 Last line should read "towards the development of pit by reducing the total amount of water".
„ 87 Fig. 23, 2nd line, for "cell" read "cells".

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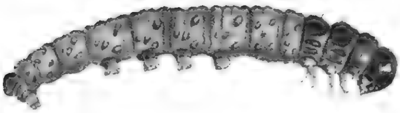
H. J. Green, Government Printer, Melbourne

PLATE 1.



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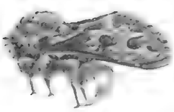

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Tasmanian Grass-grub (*Oncopera intricata* Walker) Fig. 1, larva; Fig. 2, pupa; Fig. 3, moth; Fig. 4, moth, with wings expanded. (All figures natural size.)

M. Arnold pinx.

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I. INTRODUCTION.

1. General.

The insect generally known throughout Tasmania as the " underground grass-grub " or " corbie " is the larva or grub of the indigenous moth *Oncopera intricata* Walker (Lepidoptera, Family Hepialidae).

The first reference to it in Tasmanian literature on economic entomology appears to be that of Thompson (1895), who, in a general discussion on " grass-grubs " and without designating it scientifically, gave some notes on its habits and a figure of a larva and moth. The latter, however, is clearly not that of the species in question. Six years later, Lea (1901) published a much more accurate and complete account, which he supplemented in 1908 with fuller details and good figures. In 1904, Littler contributed a brief note on its habits, without making any new facts known ; indeed, his contribution appears to be merely an abstract from Lea's first paper, although the latter's name is not mentioned.

It is the generally accepted view that *O. intricata* Walk. is the species found commonly in Victoria and in parts of New South Wales ; but this matter requires further investigation. However, under the above name, McAlpine and W. H. F. Hill (1895) published what appear to be the first notes on the early stages and habits of the mainland form. These authors did not refer to the economic importance of the pest, although they were well aware of its role in the destruction of indigenous pastures in Victoria.

French (1909), in writing of the same insect, remarked that it was without doubt the most destructive of all grass-eating grubs known to him. The inclusion of a fine coloured plate by Mr. C. C. Brittlebank and a quotation from a Departmental Report on an outbreak near Leongatha, Victoria, in 1908, add considerably to the value of his contribution.

2. Investigations carried out by the Council.

(i) *General.*—Investigations by this Council commenced in October, 1926, when the writer made a preliminary survey of the position in Tasmania. Subsequent visits were made during the following month and in January, June, September, October of 1927, and in January, 1928, with the objects of obtaining an accurate knowledge of the life history of the insect, and conducting field tests for its control by artificial means. Visits were made to Leongatha (Victoria) in April, June, August, October, November, and December, 1927, and February, 1928, and to several localities nearer Melbourne at various dates during 1927, whilst the Mt. Gambier district (South Australia) was visited in August, 1927. The object of these visits was to study the distribution and life history of allied mainland forms and to search for possible controlling agents.

Before discussing the results of investigations in Tasmania, a brief outline of the work undertaken in the abovementioned States may be given.

(ii) *Investigations in Victoria.*—In view of French's statement quoted above and the absence of more recent references in literature, it appeared that the status of *Oncopera* as a pest in Victoria had undergone some change since 1907. Through the courtesy of the Director of Agriculture (Dr. S. S. Cameron) and the Government Entomologist (Mr. C. French, jnr.) it was learned that no serious outbreaks of *Oncopera* had been reported for many years past. Mr. Thomas Crichton's farm at Leongatha, mentioned by Mr. C. French, senr. (1908), was visited in April, when the owner stated that since 1907, when his own and surrounding grazing areas were devastated by this grub, no extensive damage had been caused. Further inquiries showed that the insect is practically unknown, and nowhere in this district is it recognized as a pest. The opinion formed by farmers is that *Oncopera*, cutworms, and grasshoppers, all of which were formerly regarded as serious pests, are held in check by starlings, which, it is stated, arrived in the district in great numbers about 1908. These investigations showed that a species of *Oncopera* is fairly abundant and constitutes a minor grass-pest, and that starlings, magpies, and crows play a part in reducing their numbers. A small proportion of the grubs was found to be affected by a parasitic fungus and by a disease that was possibly of a bacterial nature, but no evidence was found of parasitic insects.

Recent investigations within a radius of 15 miles of Melbourne indicate that *Oncopera* is now a comparatively scarce insect in localities in which it was formerly abundant, but in a suburban allotment about 70 examples were located, isolated, and kept under close observation from August until December, when the moths emerged. No evidence of parasitism was observed.

(iii) *Investigations in South Australia.*—There appear to be no published records of *Oncopera* in South Australia, but through the courtesy of Mr. N. B. Tindale, of the South Australian Museum, it was ascertained that an example, now in the Museum collection, had been taken at Yawl, near Mt. Gambier, on 17th September, 1896. In August of last year, investigations were carried out over a wide area of country in this district without finding any evidence of the insect.

In Victoria and South Australia a good deal of information has been obtained incidentally concerning the life histories of *Porina fuscomaculata* Walker and *Philobota productella* Walker, two grass-eating species the larval habits of which resemble those of *Oncopera*.

From the outset it was realized that the search for effective parasites or predators of *Oncopera* on the mainland might be long and possibly fruitless. There appear to be no known insect parasites of this genus and extremely few of allied genera ; whether such exist or not can be determined only by systematic research and a much wider knowledge of the early stages than we now possess. Little is known of the eggs, egg-laying habits, and early larval stages of this group of moths, and there are many practical difficulties, associated with the capture and rearing of sufficient numbers of naturally bred and possibly parasitized larvae and pupae, yet to be overcome. It is proposed to continue these investigations in Australia, and, later, to initiate similar investigations abroad. The recent discovery in England of an ichneumon fly parasite of *Hepialus humuli*, a close ally of *Oncopera*, is of special interest in this connexion.

3. Investigations in Tasmania.

The greater part of these investigations was carried out in the Scottsdale district, where the conditions were particularly favorable for both life-history studies and experimental work. Brief visits were paid to several other districts for special purposes, and the notes obtained therein are referred to in appropriate sections of this report.

For the purpose of these investigations the types of pasture affected by grass grubs may be roughly divided into three groups, as follows :—

1. Large uncleared or partly cleared grazing areas entirely or almost entirely under indigenous grasses.
2. Second or third class grazing land, generally hilly and uncultivated, with many logs, stumps and much standing timber, sown with introduced grasses and clovers after burning off.
3. First class arable land generally held in small to medium sized blocks and laid down in introduced grasses and clovers in rotation with various annual crops.

Group 1 comprises the large sheep and cattle runs upon some of which grass grubs are regarded as the most serious pest with which owners have to contend. In many cases, pasture improvement has been found to be almost impossible and in others the attempt has been abandoned after many failures.

Group 2 comprises a considerable area of fairly good land, mostly held in small and medium sized blocks, the greater part of which are too hilly to cultivate, but are capable of producing good yields of introduced grasses and clovers. Owing to the depredation of grass grubs and rabbits, useful herbage is rapidly eliminated and is replaced by bracken fern and worthless secondary growth (Plate 6, fig. 13). Arable portions produce moderate yields of hay, peas, &c., but are too poor for continuous cropping and too small to permit of bare fallowing. When laid down in pasture they commonly become heavily grub-infested during the second year and become denuded of all profitable herbage during the next year or two. Pastures on this class of land never recover from such infestation as sometimes do those on first rate land. It is a deplorable fact that many thousands of acres in north-eastern Tasmania which were formerly under cocksfoot and other fodders are now fern-covered and abandoned wastes. To what extent grass grubs are responsible for this state of affairs cannot be determined, but these investigations strongly support the view held by most local farmers that they have been, and still are, one of the most important factors in reducing the stock-carrying capacity of some of this land to such an extent that grazing is no longer profitable. Other important factors are the ravages of "white grubs" and "army worms"; the cost of fern cutting, which, at from 5s. to 8s. per acre, approximates the rental value of the land ; and low returns for farm produce.

In Group 3 are to be found the majority of the properties upon which mixed farming, grazing, and dairying are being carried on with more or less success. The land is worth from £12 to £20 per acre, and with skilful handling is capable of producing very heavy yields. For successful dairying, and to maintain the fertility of the soil, it is necessary that a portion of the farm should be laid down in pasture, the cost of which is from £3 to £4 per acre. Under ordinary circumstances, such pastures become profitable in their second year and remain profitable for from eight to twenty years or longer, but they are often ploughed under and sown with other crops as a rotation during the sixth year or later. Under prevailing conditions in grub-infested districts, these pastures are depleted of the best grasses during the second and third years and are destroyed for dairying purposes in the third or fourth year (Plate 4, fig. 10; Plate 5, fig. 11). Top-dressing, re-seeding and good seasons may restore these pastures to something like the full value, but they are subject to reinfestation.

The possibility of discovering a practical and economically possible means of controlling this pest on the areas classified under group 1, and on most of those under group 2, by artificial methods, appeared to be so remote that is was decided to concentrate attention for the time being on the smaller and richer pastures referred to under group 3, on which the possibilities of obtaining a profitable measure of relief appeared to be distinctly more encouraging. The final and only satisfactory solution of the problem lies in the discovery and utilization of some form of natural enemy; but it cannot be too strongly emphasized that control by biological methods, if it can be established at all, involves prolonged research, and that for years to come the destruction of grass land can be only partly checked by the employment of costly and temporary methods.

II. LIFE HISTORY.

1. Egg Stage.

The egg is broadly oval in form, measures from 0.944–1.050 mm. long by 0.768–0.806 mm. wide, and is creamy white when laid, but turns dull black several hours later. The surface appears to be smooth when examined under a low magnification and is covered by a tough membrane (chorion), which serves as a protection during the long period of exposure on the surface of the ground. The number of eggs produced by an individual moth varies from 80 to 700, the average being about 500.

(i) *Duration of egg stage.*—The duration of the egg stage has not been determined under field conditions, but it is probably from 63 to 70 days, as in the case of numerous batches which were incubated under various conditions as to temperature and humidity.

(ii) *Fertility of eggs laid by unfertilized females.*—Moths collected on the wing, and therefore almost certainly unmated (see p. 16), produced fertile eggs, and in two observations the resulting larvae lived in captivity until late in September, when they appeared to be of normal size.

(iii) *Oviposition.*—Lea (1908) has already corrected the erroneous belief that the eggs are laid whilst the moth is on the wing, and has correctly stated that oviposition takes place whilst she rests upon the ground. The entire batch is generally laid together, but it may be laid in two or three groups, and nearly always in the shelter of a tussock overhanging leaves of dandelion or other plant, under bark, cow-dung, chips of wood or in holes made in loose soil by birds and bandicoots. Of twelve batches of eggs laid under natural conditions on the 6th February, 1927, four were under dandelion, one under horehound, and seven close to the butts of cocksfoot grass. The position of a recently-laid batch of eggs is often clearly indicated by the presence of a mass of scales detached from the parents' body during the violent fluttering that accompanies the act of oviposition. There appears to be a disposition to select patches of long and rough grass in which to oviposit where such exist in proximity to closely-grazed areas. This was noted particularly where there existed matts of dry "silver grass" in pastures largely composed of short cocksfoot and rye. But whatever may be the attractiveness of long grass, it does not appear even to be sufficiently strong to induce moths to deliberately leave a closely-cropped paddock for a well-grassed one in the vicinity. A note from Longford is of interest here. When top-dressing a heavily-stocked old pasture paddock in the autumn of 1926, the owner left one "land" in the middle untreated as a control block. During the following spring and summer the stock (sheep and cattle) kept the top-dressed portion closely fed down, but avoided the untreated "land," resulting in a considerable carry-over of dry grass in February and March, when the moths would be on the wing. In the following August, the control block showed unmistakable signs of heavy infestation; and in January of 1928, when the writer visited the farm, it was in a deplorable condition, whilst the remainder of the field was only slightly damaged. The assumption was that the moths had concentrated their attention on the control block when ovipositing in February and March of 1927 and that the resulting grubs had brought about the conditions noted subsequently. It would seem reasonable to suppose that the concentration for a period of several months of many head of stock on the top-dressed area would account to some extent for its freedom from grubs.

2. Larval Stage.

(i) *The larvae and its habits.*—The larvae at hatching measure about 2.88 mm. in length; the head and upper surface of the first thoracic segment is dark brown, the legs greyish, and the body creamy white, with numerous minute greyish tubercles. Observations carried out on experimental plots of rye grass showed that during the first two days of their life they live as a community under a light silken web over and amongst the surrounding loose soil and debris and that, on the third day, young grass in the near vicinity is attacked, either by grubs which emerge from the shelter of the web or by others which have migrated outwards and have commenced an independent existence under their own covered ways, which by now may be $\frac{3}{8}$ in. long by $\frac{1}{8}$ in. wide and encircle the stem of a young grass plant. In either case, the plant is cut through at ground level, the upper portion being partly devoured and partly used to extend and strengthen the covered way, and the lower gnawed away to a depth of ½ in. or more below the surface, leaving a small vertical hole which forms the commencement of the characteristic larval burrow. Other migrating larvae form covered ways of silk and earth over a shallow chamber excavated in the soil in which they may shelter, feeding on surrounding plants, before commencing to burrow more deeply. Others again live for a week or two on the surface under a leaf or surface debris or under a very fragile web, through which they are clearly visible by day.

By the end of the first week, some of the larvae have scattered widely from their original position and have nearly doubled in length, but they have changed but little in general appearance, excepting that the body appears to be light greenish or greyish white in colour, due to presence of food in the intestines. Some are now to be found head downwards in isolated vertical burrows about ½ in. deep, and others in their original position or in small scattered colonies under a common shelter. The burrow, which is characteristic of the larvae of this group of moths, is thus commenced at a very early stage of the insect's existence, and is deepened and widened throughout the winter and early spring. It is a common belief that the grub feeds on the roots as well as upon leaves and stems, but Lea has correctly stated that this is not the case, and gives convincing evidence in support of his statement.

At one month old, the most advanced larvae are about 7/16 in. long; the head, legs, thoracic plates, and tubercles are distinctly darker, and the body is clothed with scattered long hairs, but in other respects it closely resembles the younger stages. The destruction of the young grass is now very evident throughout the plots and particularly in the vicinity of the now greatly extended web-covered area which originally sheltered the whole brood, but which now contains but a few dozen individuals. During feeding, the covered ways are extended to, and around, new plants which are cut off under protection of the web and allowed to fall to the ground, where they are either eaten or built into the covered way, whilst the stem is destroyed down to the root. At the end of the second month (end of May), the largest larvae are about ⅝ in. long and are found in burrows about 1 in. deep or under surface webs or debris in the observation plots and in the butts of the tussocks of grass in the field.

By the middle of June, the largest larvae have attained a length of about 1 in., and are to be found in typical burrows at a depth of from 3 in. to 4½ in., but the majority are considerably smaller, ranging from 5/16 in. to 9/16 in. in length, and are generally concealed in the butts of the tussocks. The damage as yet is hardly appreciable in the field, excepting for that caused by the larger examples, but there is abundant evidence that the young growth, as well as the woody portions of the stem and the enveloping leafy sheaths, are being attacked. Closely-cropped tussocks, particularly of native grasses, cocksfoot and frog-grass, are now slightly or extensively covered with a mass of excrement, vegetable debris and earth woven together, under which much of the feeding takes place. As this appeared to be the earliest stage at which the pest could be attacked with poison sprays with any prospect of success, arrangements were made for the first series of tests, which were commenced on 21st June and concluded on 24th June.

The irregular development of the larvae is very noticeable from the middle of June to the middle of August; thus collections made on 1st July contained examples ranging in length from $\frac{5}{8}$ in. to $1\frac{1}{4}$ in. (the latter at a maximum depth of 6 in. in the soil), and on 8th August from $\frac{3}{4}$ in. to $1\frac{3}{4}$ in. The latter are nearly full grown and may be described as greyish or leaden in colour, with several darker coloured tubercles on each abdominal segment, dark brown head and thoracic plates and light brown legs and prolegs.

From the beginning of August, the larvae become increasingly destructive until about the beginning of November, when the most advanced are full grown, i.e., from $1\frac{7}{8}$ in. to 2 in. in length, and cease feeding (Plate 1, fig. 1).

During the first week of September, the grubs are from $1\frac{1}{4}$ in. to a little over $1\frac{3}{4}$ in. in length, and are found in burrows varying in depth from $3\frac{1}{2}$ in. to 6 in. About this time the latter were being deepened at an unusual rate, judging from the quantity of freshly turned soil which had been brought up from below and spread over and around the covered ways and over the closely-cropped infested tussocks. Whether this activity was due to more favorable conditions for burrowing brought about by recent rain, or whether it is a normal occurrence, could not be determined, but the effect was to render the shorter and denser tussocks, already often covered with a mass of web, earth and debris, still more impervious to the sprays used in the second series of tests, which commenced on 10th September. Whilst the majority of the burrows are situated in or near tussocks and are protected by a common covering of earth and debris, many are to be found under cow-dung, pieces of wood, matted accumulations of dry grass (generally worthless indigenous species), and in more or less open spaces. In the latter case, the burrow is protected by a covered way, under which will be found in most cases a shallow chamber or vestibule about $\frac{1}{4}$ in. deep and large enough to permit of the grub turning freely. This vestibule is in close proximity to the entrance to the burrow and communicates also with one or more tube-like extensions of the covered way, which enable the grub to attack plants in the vicinity without unnecessary exposure. The appearance of infested tussocks before and after removal of the surface protection is illustrated in Plates 2 and 3.

The burrow and surface of the soil beneath the covered way is lined with a densely-woven brownish silken film (Plate 4, fig. 9), which persists in the former until after the emergence of the moth. In all cases the excrement is deposited at some little distance from the vestibule and entrance to the burrow, either in a densely packed heap under the covered way or on the exposed surface of the ground beyond its margin.

If the burrow is situated at some little distance from the nearest food plant, a tube-like extension of the covered way is generally formed to connect the two. This tube may vary in length from a few to 4 or 5 in., but it is often dispensed with, and the feeding ground may extend over an unprotected area of 6 or more inches.

When occupied by full-grown larvae the burrows vary from $5\frac{1}{2}$ in. to 12 in. in depth, but the vast majority range from 8 in. to $8\frac{1}{2}$ in. (3 in. to 6 in., generally 4 in., in hard ground and seldom less than 9 in. and frequently more than 12 in. in soft ground, according to Lea) and are about $\frac{1}{4}$ in. in diameter. That denseness or looseness of the soil is not the factor that determines the depth of the burrows is shown by the fact that they were found to be of average depth in a deep sandy loam, in deep volcanic loam, on a black soil flat, on a stiff grey soil with dense clay subsoil at 4 in., and on a disused bush track in the same paddock. In Victoria, an allied species was found at 9 in. in dense clay underlying 6 in. of stiff grey soil and at 6 in. to 8 in. in light loam and in heavy volcanic soil.

(ii) *The non-infestation of certain soils.*—The reason for the comparative immunity of certain pastures from infestation has not been satisfactorily explained. It is well known that many existing first-class pastures have survived heavy infestation during their early years and have subsequently recovered and remained practically free from the ravages of this pest for long periods. Such recoveries appear to be confined to first-rate land. Headlands, roadside grassland, and small paddocks adjacent to farm buildings are rarely badly infested, even though fields in close proximity be devastated. Low-lying land, especially if clayey, is often but lightly infested, but some of the richest alluvial land in Tasmania is as heavily infested as the poorest sandy soil and the richest of the well-drained volcanic soils. Fertile hillsides and flats, apparently regardless of the nature of the soil, are equally subject to infestation; in fact no district or soil appears to be entirely free from the pest. On the Lower Tamar there is a small heavy alluvial flat surrounded by low hills, said to be of limestone formation, which, though margined by grub-infested slopes, has never been attacked. It was suggested that the supposedly alkaline nature of the soil might offer an explanation of this fact, but upon examination of samples it was found to be very acid (pH 4.57), as were the following heavily-infested soils from Scottsdale, viz., blackish granite sand (pH 4.02), brown sandy loam (pH 4.57), and first-class volcanic soil (pH 5.17).

(iii) *Feeding habits and food.*—Ordinarily, healthy larvae are found on the surface of the ground only between the hours of 9 or 10 p.m. and daybreak; exceptionally, as during a fall of rain or when the burrows are situated under a piece of wood, cow-dung or other object which may be turned over rapidly, they may be surprised there during the day under the covered way or other protection. Feeding, however, is not confined to the hours of darkness, since it is a common occurrence to find grass and other food gathered and stored in the covered ways earlier in the process of being devoured during the day.

Feeding takes place whilst the larvae rest more or less horizontally on the ground or closely cropped grass. Shorn off near the butt, the grass falls to the ground to be eaten there, or drawn into the covered ways for future consumption or to remain, as in the case of some native annual species, as a closely-matted surface covering.

All varieties of grass and herbs ordinarily sown for pasture are attacked, including the clovers. Rye grasses are generally attacked first and, together with cocksfoot, are generally almost completely eliminated from the field during the second and third year after sowing. Cocksfoot is not readily attacked in some districts, but in others, in the absence of rye grass, it is the first to suffer. The clovers are generally passed over in favour of grasses, but often suffer appreciable injury whilst there is yet an abundance of the latter. Sorrel and dandelion are rather less attractive than clover, whilst thistles appear never to be eaten. Mosses, indigenous grasses, and other small plants, appear to be their natural food, but in times of great scarcity reeds, rotten wood, and other surface vegetable debris, including cow-dung, are devoured. Grain crops generally escape damage merely because routine farm practice is an effective control against this pest, but under certain conditions very extensive damage may occur, as the following record indicates :—In December, 1927, it was reported that 30 acres of grassland on Mr. Horace Young's farm at Longford became badly infested during the second year after sowing, and in November, 1926, when the grubs must have been nearly full-grown, one half of it was fallowed, whilst the other was left in grass. During the following June, the grassland was ploughed, and within the week, the whole area (30 acres) was sown as a continuous block with wheat. In August, the owner noticed an increasing thinning out of plants on the unfallowed block, and upon closer examination found that they were being cut off at ground-level by *Oncopera* larvae. This destruction continued until the ears appeared, and at harvesting the loss in grain was estimated to be one-third of the crop. An investigation by the writer on 1st February confirmed the report as to the identity of the insect concerned and the extent of the damage and appeared to definitely establish the following facts :—(i) the November ploughing had either destroyed the then mature, or nearly mature, larvae or prevented effective re-infestation of the land during the following summer by the resulting moths, or by others from adjoining headlands and paddocks ; (ii) when the second half was ploughed in June, young larvae resulting from eggs laid in February or March, were turned under with the grass, upon which they subsisted until the new growth (wheat) enabled them to return to their normal surface feeding habits. It was noticed particularly that none of the burrows found on 1st February were deeper than the depth of the ploughing (5 in.). The effects of fallowing on eggs, larvae, and pupae are discussed further on in this report ; but it may be remarked here that a period of bare fallow should precede the sowing of crops or grass on land previously under susceptible crops. In addition to sown and indigenous pastures, lawns are frequently attacked and often seriously damaged, whilst carrots, onions, and strawberry plants are sometimes molested.

(iv) *Migration.*—Lea states that "from the time the grubs are half-grown till their final change, however, it is certain that each grub constructs only one tunnel." Whilst proof to the contrary is wanting, there is very strong evidence that a partial migration involving the construction of new tunnels does occur under certain conditions, as, for example, when a particularly heavily-infested area becomes denuded of food before the grubs have become full- or nearly full-grown. Specific instances were investigated in 1927 at Rosny Golf Links, near Hobart, at Cressy, and at Scottsdale, in each of which there was every appearance of a definite advance from the original site of infestation and progressive destruction of the pasture, as had been reported by those who had the areas under observation throughout the season. It is the writer's present opinion that it is not an unusual occurrence for these grubs to be forced by starvation to leave the original burrows and to construct fresh ones in more favorable positions; that the advance is not in the nature of a general migration, as in the case of the army worm, but is undertaken by individuals acting independently, and does not involve the whole grub population of a devastated area; that the advance is by short stages and may involve the construction of even a third burrow; and that grubs do not migrate from a ploughed field.

Observations on Tasmanian, Victorian, and South Australian forms of *Oncopera* have shown that nearly full-grown larvae, if removed from their original burrows, will construct others of normal depth even in hard soil. The following observations are of interest in this connexion. In August and September larvae were located by means of their covered ways and destruction of grass in their vicinity in buffalo grass and indigenous grass lawns in Melbourne, and were isolated by pressing into the soil the cut edges of galvanized iron collars 8 in. to 12 in. in diameter by 3 in. to 8 in. deep (with or without wire gauze covers). In each enclosure there was abundance of grass and ample feeding range, as shown by the fact that some of the grubs completed their development and emerged as moths in December. Nevertheless, in several instances, the grubs left the original burrow, constructed a new one within the enclosure and, later, tunnelled under the collar and constructed a third without, in which they completed their development at a normal depth in the soil.

"This matter," as Lea remarks, "is more important than appears at first," and is discussed here at some length in the hope that it will stimulate further observation on the part of graziers.

The density of the grub population varies very greatly in different parts of the same field. In native pastures, two or three grubs to each square foot might be regarded as a moderately heavy infestation, but it is often greatly exceeded, whereas in sown pastures twelve to the square foot or from five to nine to a single three-year old plant of cocksfoot is of quite common occurrence.

3. Pupal Stage.

The larvae begin to reach maturity early in November, when they cease feeding and allow the covered ways to collapse on the otherwise open burrows. After evacuating the contents of the intestines and shedding the skin, they are creamy white with light-yellow head and blackish mouth parts; the dark horny plates on the thorax and the tubercles on the abdomen disappear, but the scattered reddish hairs remain; nine pairs of spiracles (external openings of the air-tubes) are now clearly visible as dark elongated spots, one on each side of the thorax above the forelegs and one on each side of the first eight abdominal segments. Seventy-five per cent. of the larvae examined at Scottsdale from 28th November to 1st December were in this condition. Later by a process of straightening out and contracting (to a length of from $\frac{7}{8}$ in. to $1\frac{1}{8}$ in.), the larvae begin to assume the appearance of pupae, but lack the dark colour and characteristic features of the latter. This stage was found abundantly in the above district from 27th December to 5th January, rarely three weeks later, and, finally, on 3rd February. The first pupae were found on 5th January (none could be found on 27th December), when the proportion of larvae and pupae were approximately equal. The pupa (Plate 1, fig. 2) varies in length from $\frac{7}{8}$ in. to $1\frac{1}{8}$ in. and in width from 3/16 in. to $\frac{1}{4}$ in. The eyes are yellowish brown, thorax and wing sheaths dark brown, abdomen yellow to light brown; the first segment is visible only from above; segments two to eight are clearly visible, as are their spiracles; segments nine and ten are very small and closely fused. To facilitate their movements in the burrows, the pupae are armed with comb-like processes and rows of teeth on some of the abdominal segments. Their arrangement is as follows:—On the upper surface a double row of short stout spines on segments three to six, four rows on the seventh, three rows on the eighth, and a roughened horny plate on ninth; on the under surface there is a comb-like process on segments four to six, on the seventh a somewhat similar process, but bearing a continuous row of larger spines.

The pupae are not enclosed in cocoons, but are naked and capable of moving upwards and downwards in the burrows in which they, like the larvae, are always found head uppermost.

4. Moth Stage.

(i) *Emergence from the pupae.*—Under natural conditions, the majority of the moths emerge from the pupae between 6 p.m. and 7 p.m. A few, however, defer their emergence until 8 p.m. or a little later. When about to emerge, the pupae makes its way to the surface, pushes its way through the surface covering, if any, and rests generally with the thorax projecting from the burrow until the moth bursts through the hard enveloping integument and crawls away a few inches, leaving the discarded pupal skin either in the burrow or on the surface of the ground. In this position, the newly emerged moth rests perfectly motionless and almost impossible to rouse until the mating flight commences. Until this moment, it can rarely be induced to use its wings, even when thrown into the air. Occasionally a moth may be flushed from the ground a few minutes before the mating flight commences, but its flight is generally short, though sometimes long enough to rouse a few others in a preliminary flight of short duration.

Occasionally, pupae have been noticed to appear on the surface as though about to transform, then retreat into the burrow until transformation took place several nights later.

(ii) *Description of moth.*—The moths are dull greyish brown with forewings more or less boldly marked with a curiously involved pattern in a light grey or whitish colour, and the hind wings mostly of uniform greyish brown (Plate 1, figs. 3 and 4). The male, easily distinguished by its plumose hind legs, is always more brightly coloured than the female, in which the wing markings are commonly very obscure. The mouth parts are greatly reduced and not adapted for feeding; the antennae are reddish brown, short and rather stout; the eyes large and nearly hidden by the long brown hair-like scales on the face; the thorax densely clothed with long scales like those on the face and the wings in repose carried roof-like and pressed closely against the body. Except whilst on the wing, the insect rests horizontally on the ground, never, apparently, vertically on fence-posts or other objects.

There is a noticeable variation in size. A long series of males and females collected in 1927 and 1928 give the following range:—With wings expanded, males $1\frac{1}{8}$ in. to $1\frac{5}{8}$ in., females $1\frac{1}{4}$ in. to $1\frac{3}{4}$ in.; length with wings folded, males $\frac{5}{8}$ in. to $\frac{7}{8}$ in., females $\frac{7}{8}$ in. to $1\frac{1}{8}$ in.

(iii) *Seasonal appearance of moths.*—Lea (1908) states that the first moths are to be seen early in January, and the last early in March. In the Scottsdale district, moths were first noticed on 24th January in 1927 and on 21st January in 1928, and the last on 18th February in 1927, and on 2nd February in 1928. In 1927, they appeared to have reached their maximum abundance about nine days after the first were seen, and by the 12th day about 60 per cent. had emerged. In the Longford district, in 1928, no moths had emerged either from grass or stubble land up to 1st February, but were reported by a local observer to be on the wing from 8th February to 20th February.

(iv) *Proportion of the sexes.*—Examination of pupae and recently emerged moths indicated that the sexes are produced in approximately equal numbers, but as some of the females do not fly and as some males survive from the previous night, the latter always predominate in collections taken on the wing. During the first few minutes of the flight, 40 to 50 per cent. were found to be females, but the percentage diminishes rapidly as the flight reaches its zenith and begins to wane. Thus of 407 moths collected on three nights during the period of maximum activity, i.e., 7.45 to 8.5 p.m., 399 were males.

(v) *The mating flight.*—One may walk over heavily-infested land before the flight commences and have difficulty in finding a dozen moths where hundreds could be swept up in the net a few minutes later. They are not in the burrows, as some believe, but lie on the surface entirely exposed or, at the most, only partly hidden by grass or other herbage, relying upon a dull light and their protective colouring to save them from detection by their enemies. The flight commences between 7.30 p.m. and 7.45 p.m. (the average for seven nights in 1927 and 1928 being

7.40 p.m.), and generally lasts for from 40 to 55 minutes (the average duration of flights on seven nights was 41 minutes). The first intimation that the flight is about to commence is generally the appearance of a few moths flying rapidly backwards and forwards over the tops of the grass. Within a minute or two, tens of thousands rise and join in the flight, which is accompanied by a very audible humming of wings. Contrary to the habit recorded of some allied moths, the males seek the females, either amongst those on the ground, flying low on the grass, or, rarely, flying at heights up to 30 feet or more. About five minutes after the flight commences, the majority of the females are either mated or to be found fluttering excitedly on the ground or low grass, where they are sooner or later pounced upon by males. Commonly, from several to twenty males compete in a struggling mass for a single female, and in many cases similar masses comprise males only. Copulation usually occupies about five minutes, after which the female, now often almost denuded of scales, seeks the shelter of a tussock or other cover under which to deposit her eggs ; whilst the males fly away but little damaged to seek other females. Oviposition appears to take place about an hour to three hours after mating. The average length of life of the male has not been determined, but it is certain that many live to take part in the following night's flight. The female, on the other hand, rarely lives longer than twelve to fourteen hours, and it is extremely improbable that she ever lives to take part in a second flight. It is certain, at any rate, that she produces but one batch of eggs, and that after this batch is laid she is never again capable of reproduction.

On calm nights, the moths fly backward and forward over the ground at a height of from 3 to 12 inches, rarely rising higher and rarely leaving the paddock in which they were reared. On windy nights, however, they have been seen to rise to a height of 20 to 30 feet or even more, and in couples, threes or fours fly with the wind, across an adjacent road and fallowed paddock and fall on grassland 300 to 400 yards distant. On several occasions, such pairs and groups were captured in the net either in full flight or as they fell to the ground together, and in every instance were found to comprise a male and a female or a female and two or three males. Such flights as these would readily account for the heavy isolated infestations of small extent so frequently observed in otherwise lightly-infested paddocks.

III. EXPERIMENTS ON METHODS OF CONTROL.

1. Egg Stage.

The artificial control of this pest in the egg stage does not appear to be practicable, for the following reasons :—The batches are generally deposited together in more or less sheltered positions ; during the incubation period some of the batches are further concealed by the trampling of stock and the growth of herbage ; effective sprays are costly to prepare and apply and could be used only on certain classes of land ; fire could be employed only in rare instances and may cause serious loss to the pasture, fences and adjoining properties. The latter method is reported to have been tried and to have given very variable results, but no details as to dates, nature of grass, and subsequent effects on the pastures are obtainable. Experiments with suitable controls should be carried out between the latter part of February to the end of March to determine the effect of this treatment.

Spraying.—Experimentally it was found that the two undermentioned sprays destroyed 100 per cent. of eggs, but both caused very severe foliage burning :—

(1)	Dinitro-o-cresol	3.25 gms.
	Crude naphtha (sp. gr. 0.885)	565 cc.
	Hard yellow soap	97 gms.
	Water	19½ litres.

(2) As above with light tar oil (sp. gr. 0.925) 540 cc. substituted for crude naphtha.

2. Larval Stage.

(i) *Spraying.*—Arsenical sprays appeared to offer a means by which the larvae could be effectively and economically destroyed on cleared land of high grazing value. To determine the earliest stage at which satisfactory results could be obtained, larvae were kept under observation in experimental cages and in the field from 30th March until 15th June, when the writer left for Tasmania to carry out the first of a series of field tests. Prior to the latter date, many laboratory tests were made in Melbourne with young larvae in pots of rye grass, the object being to ascertain the minimum effective dosages of lead arsenate and calcium arsenate, the sprays proposed to be used in the field.

The equipment used in the field experiments was a Cooper " Perfect Balance," 2 horse-power orchard spraying outfit with vat of 100 gals. capacity, mounted on two wheels and drawn by one horse (Plate 6, fig. 14). A boom 6 ft. long and capable of vertical adjustment was substituted for one lead of hose, the other being fitted with a Myers spray gun. The boom carried six Friend nozzles which, when set at from 11 in. to 18 in. from the ground, effectively covered a strip 9 ft. wide. During calm weather, nearly all the plots were sprayed from the latter height, but in windy weather it became necessary to reduce the height to 11 in. The spray-gun was used only where the presence of logs, stumps, ditches, &c., prevented the use of the boom. The pressure maintained throughout ranged from 200 to 250 lb. per square inch and averaged over 225 lb. The output of spray fluid was 100 gallons per 19 to 23 minutes (average 20 mins.) and the petrol consumption from 0.8 to 1.0 pint per 100 gals. The greatest area sprayed during one day was 9 acres, which occupied two men for six hours. With a better arranged water supply and working ordinary farm hours, the area could have been increased to 14 acres per day without difficulty. A still larger area could have been dealt with by using an 8 ft. boom and two additional nozzles, which is well within the capacity of the outfit.

The spray was used in all trials at the rate of 100 gals. per acre, which appeared to be the minimum quantity required to thoroughly wet the foliage.

The materials used in the first tests were commercial brands of calcium arsenate (powder) and lead arsenate (powder and paste). The former was intended for use as a dust, but as a satisfactory distributor was not available it was used as a spray, at the rate of 3 lb. and 4 lb. per 100 gals. of water, without the addition of lime or spreader. Arsenate of lead was used at 2 lb., 2½ lb., and 3 lb. of powder per 100 gals. of water and at 6 lb. of the paste form per 100 gals.

In the second series, arsenate of lead was used in strengths of 3 lb., 3½ lb., 4 lb., and 5 lb. of powder and 7 lb., 7½ lb., and 12 lb. of paste per 100 gals. of water. In some of the tests, skim milk and raw linseed oil were used as spreader and adhesive respectively.

Eighteen and three-quarter acres of sown pasture were sprayed in the first series of trials (June) and 13 acres in the second (September). Experimental blocks, with the necessary control blocks, were selected in fields which were considered to be representative of the better classes of land in the district. These fields may be described as follows :—

Field 1.—Apparently very lightly-infested, old, short, and dense pasture, consisting of rye, cocksfoot, and clovers on first-class red soil.

Field 2 (Plate 4, fig. 10).—Very heavily-infested pasture on similar soil to the above, laid down four years previously in cocksfoot and clovers ; thin and very patchy as a result of grub infestation during the previous season ; expected by owner to be completely destroyed during the approaching spring : closely fed-down by sheep at time of spraying.

Field 3 (Plate 6, fig. 12).—Heavily-infested two and three years old cocksfoot and clover pasture on fertile, moderately stiff and sandy loam, rather patchy as a result of grub infestation during the previous season, moderately closely fed-down by cattle, but with patches of rough dry grass, scattered bracken fern and blackberry in parts ; expected by owner to be seriously depleted of grass during coming spring.

Field 4.—Very heavily-infested three years old cocksfoot and clover pasture ; on first-class land similar to Fields 1 and 2 almost denuded of useful herbage by grubs during the previous year, but at time of spraying carrying a dense mat of weeds and much young clover.

Two acres of Field (1) were sprayed in June, but as the results were inconclusive, due probably to the fewness of the grubs infesting it, this area is not referred to again in this report. Three acres were sprayed in Field 2 in June and one-half acre in September. In Field 3, 13¾ acres were sprayed in June and 11½ in September, and in Field 4, 1 acre in September only.

Owing to the irregular distribution of grubs in different parts of the same fields and blocks, it was found impracticable to make an approximately accurate census of the population for the purpose of checking the results of experiments. It was thought that a count of living and dead grubs firstly and, later on, a comparison of the pasture on sprayed and unsprayed blocks would give a fairly satisfactory indication as to the effects of treatment. Actually, only the latter method was available, for reasons stated further on.

First series of trials (June).—Spraying was carried out on four successive fine days, commencing on 21st June, which were preceded by more than a week of very severe frosts and cold wet weather, and followed by five successive heavy frosts and eight days of light showers or heavy rain. The majority of the grubs at this period are from 5/16 in. to 9/16 in. in length, and are situated, for the most part, in the butts of tussocks, whilst a few larger examples, ranging up to 1 in. in length are to be found inhabiting vertical burrows from 3 in. to 4½ in. in depth.

The experimental blocks were under observation for from thirteen to sixteen days after spraying terminated, and were examined again in September, October and January following. In addition, tussocks of cocksfoot and fog-grass were dug out of the pasture after spraying and were kept, with a similar number of controls, under observation, for eight days in an open shed. When these were examined, the sprayed tussocks were found to contain a total of 85 grubs, of which number, 50 (approximately 58 per cent.) were dead and 35 (approximately 41 per cent.) alive. The percentage of deaths in tussocks sprayed with 2 lb.–100 gals. arsenate of lead (powder) was 66 per cent. and in those sprayed with 3 lb.–100 gals. of the same poison only 57 per cent. From a similar number of unsprayed tussocks, 49 grubs were taken, of which eight (approximately 16 per cent.) were dead. Since it was impossible to determine the percentage of deaths due to poison, mechanical injury and other causes, and the number of grubs which had fed during the eight days on sprayed and unsprayed portions of the tussocks, no conclusions can be drawn from these observations.

Results of first series of field trials.—The results generally were unsatisfactory. A spray containing lead arsenate 2 lb.–100 gals. (powder) gave very poor results, but there was better control as the dilutions increased in strength to 3½ lb.–100 gals. Calcium arsenate (powder) at the rate of 3 lb. and 4lb.–100 gals. gave more definite results during the first four or five days after spraying but the final results did not compare favorably with those obtained with lead arsenate. In September, all the sprayed blocks showed some improvement over the unsprayed blocks, but in none of them could the results be regarded as anything but disappointing. Failure is attributed to the following reasons :—(*a*) More than 50 per cent. of the grubs appeared to be feeding at or below ground level in the butts of cocksfoot and other tussocky grasses, under the shelter of overhanging foliage, or under cow-dung and other objects, where they were exposed to little risk of poisoning; (*b*) many of the grubs were immobilized and incapable of feeding as a result of frost; (*c*) only from one to three nights were available for feeding on poisoned foliage before further severe frosts and, later, rain set in, the former freezing the herbage and surrounding soil and tending to further immobilize the grubs, the latter gradually washing off the spray and promoting new and consequently unsprayed growth.

Twelve days after spraying, an attempt was made to ascertain the proportion of dead to living grubs in the various blocks, but this was abandoned owing to the impossibility of distinguishing between benumbed, dying and injured individuals, and of estimating the number of dead and dying which were picked up by birds on or near the surface.

Second series of field trials (September).—Due to the absence of insufficient rain and, to a lesser extent, ravages of grubs, the amount of herbage on the experimental blocks was found to have increased but little since June; there was, however, a marked increase in the number of tussocks showing external evidence of grub infestation. A preliminary examination showed that a considerable proportion of the grubs, now from $1\frac{1}{4}$ in. to $1\frac{3}{4}$ in. in length, were feeding almost exclusively on the woody butts of cocksfoot, and other grasses under protection of their covered ways and surface tubes. It appeared then, as it does now, that this habit must militate against complete control of the pest, either by sprays or dusts, in pastures where such plants predominate, until some practicable method is found for removing this protection before insecticides are distributed. Experimentally it was found that brush harrows failed to effect this object satisfactorily. The possibilities of obtaining better control by increasing the output of spray fluid and the pressure under which it is delivered have yet to be tested.

The various blocks were sprayed under very favorable conditions on 10th, 12th, 13th, and 15th September, and were under observation until 22nd September, again on 2nd November, and again on 30th January following.

Results of second series of trials.—The first results of spraying were noticed on 14th, four days after a block had been sprayed with lead arsenate $5\frac{1}{2}$ lb. (powder) to 100 gals., and on 16th three days after spraying with lead arsenate $7\frac{1}{2}$ lb. (powder) and 12 lb. (paste) to 100 gals. On these dates, many affected grubs were found on or near the surface, from whence they were being gathered by starlings, magpies, and crows. Dead and dying grubs were found on the surface and in the soil until observations were suspended on 22nd September, on which date there were to be found in all the sprayed blocks a large number of apparently unaffected, or only slightly affected, individuals and abundant evidence of poison on the herbage, other than the most recent growth. Recently gathered poisoned leaves were found in many of the burrows occupied by apparently healthy grubs, indicating that further mortality would occur.

When examined on 2nd November, most of the sprayed blocks showed considerable improvement over the controls. Throughout the district, however, the pastures were backward as a result of insufficient rain.

The best results were obtained in Field 2, in which $7\frac{1}{2}$ lb. and 12 lb. (paste) gave a control considered to be in the vicinity of 75 per cent. and 90 per cent. respectively.

In Field 3 the results with 4 lb. (powder) and 7 lb. (paste) were generally similar to that obtained with $7\frac{1}{2}$ lb. (paste) in Field 2, but wherever there was much old grass there were badly infested patches. In one of the two blocks sprayed with 3 lb. (powder) the results were comparable with the above, but in the other many grubs appeared to have escaped destruction. The apparent difference in the results could not be satisfactorily accounted for.

(ii) *Fumigation.*—Soil fumigation cannot be regarded as a practical means of controlling this pest on grazing land, but it appeared probable that it could be employed successfully on small lawns. The trials recorded below were undertaken with the object of obtaining some data for use in another connexion. *Calcium cyanide* (*Cyanogas Flakes*).—Experiments were carried out on 29th November and 1st December in first-class dry red friable volcanic soil of considerable depth. In plots 1 to 5, the soil was removed to a depth of 4 to 5 in., and after sprinkling the flakes evenly over the undisturbed surface below this depth the loose earth was replaced and trampled down as firmly as its nature would permit. In plots 6 to 8, grass and weeds only were removed, after which the flakes were evenly distributed over the surface and dug in to a depth of about 4 in. All *Oncopera* grubs exposed in these operations were removed prior to fumigation. The soil temperature at 6 in. from the surface was 70° F. in plots 1 and 2 and 65° F. in plots 3 to 8. Of 193 grubs gathered after fumigation, 90 (approximately 46 per cent.) were in the stage immediately preceding the final moult and 103 (approximately 53 per cent.) in the stage immediately following. The results of fumigation are shown in the following table :—

No. of Experiment.	Dosage per square yard.	Duration of fumigation hours.	Grubs per plot.			Percentage killed.
			Living.	Dead.	Total.	
	oz.					%
1	1	51	5	5	10	50·0
2	2	51	0	13	13	100·0
3	2	48	1	32	33	96·9
4	4	48	0	32	32	100·0
5	6	48	0	42	42	100·0
6	2	48	3	20	23	86·9
7	5	48	2	25	27	92·5
8	7	48	0	13	13	100·0

Fumigation was effective for from 2 in. to 5 in. laterally from the boundaries of the plots, and as the soil was still heavily charged with cyanide gas the range may have been increased had the examination been deferred a day or so longer. In addition to *Oncopera*, white grubs and wireworms—the larvae of an Elaterid beetle—were present in all the plots and were 100 per cent. destroyed by fumigation.

A second series of trials was made concurrently with the above in which dosages of ½ oz. and 1 oz. were placed in crowbar holes 6 in., 9 in., and 10 in. deep in the vicinity of heavily-infested tussocks of cocksfoot. Two days later, the fumigant was found in almost unchanged condition and the grubs unaffected. Believing that the probable causes of failure were the dry condition of the soil and the brief duration of the test, a further experiment was carried out on 13th September following, when the soil was moist and registered a temperature of 58° F., rising to 65° F.

during the following eight days. A plot 16 feet square, with crowbar holes 2 feet apart and 5 in. to 6 in. deep, was fumigated with calcium cyanide dust (Cyanogas "A" Dust) at the rate of 1 oz. per hole. On 22nd September, the condition of the fumigant and grubs was as recorded above, excepting that a few of the insects which were in close proximity to the chemical were destroyed. On 2nd November, when the final examination was made, much of the chemical still remained, but there was no evidence of grub control beyond a radius of 6 in. from each charge.

Cyanogas flakes were further tested in November in a field which had been laid down in grasses less than three years previously and which, in the interval, had become almost denuded of useful grass owing to the ravages of grubs. The soil, a light volcanic loam, was dry and warm (70° F.) and broke loosely on ploughing. The flakes were sown at the rate of about 350 lb. per acre by hand in the bottom of the preceding furrow and were covered at once by the following sod. Five days later, 98 per cent. of the grubs were found to be dead.

Dichlorobenzene—a proprietary preparation, the active principles of which are said to be paradichlorobenzene and orthodichlorobenzene—was tested in September in Field 4 in two small plots heavily infested with *Oncopera* and "white grubs." The soil was moist and registered a temperature of 58° F. The plots were 16 feet square with crowbar holes 2 feet apart and 5 in. to 6 in. deep, and 15 feet square with barholes 3 feet apart and 5 in. to 6 in. deep respectively. The fumigant was used at the rate of ½ oz. per hole in both plots. When examined on 2nd November, the destruction of grubs was found to be negligible.

(iii) *Dusting.*—Calcium arsenate was tested on a ¼-acre block in Field 2 on 16th September and on a smaller area in Field 4 on 12th September. Distribution was made with a Root Hand Dust Gun—a thoroughly effective appliance. The smaller block was dusted at the rate of about 15 lb. per acre on a calm, dewy morning, permitting of even and ample distribution of the insecticide over the foliage and surface debris without waste of material. After several postponements, due to unfavorable weather conditions, the larger block was dusted at the rate of 48 lb. per acre at 6 a.m. during a period of alternating calms and strong breezes from constantly changing directions, resulting in very uneven distribution and much waste of material. Both blocks were heavily infested with *Oncopera* larvae and, in addition, white grubs were particularly abundant on the smaller. Heavy rain fell on the night of 21st and following day, washing off most of the dust. On the 22nd, dead and dying *Oncopera* were found on both blocks, particularly in the larger, while in the former there were many affected white grubs. On the 2nd November, it could be stated definitely that the control of *Oncopera* on the large block was very satisfactory and better than that on an adjoining block which had been sprayed on 13th September with lead arsenate (paste) at 12 lb. per acre; whilst on 30th January, following abundant rain in December, this block carried more grass than any of those under observation. On the smaller block, however, *Oncopera* were exceedingly plentiful on 2nd November, although white grubs had been almost completely exterminated.

Writing on 26th March last on the results of the experiments carried out in Field 2 generally, a local farmer and keen observer stated that "apart from the grass being a little thin in some places it is one of the best paddocks of feed about here."

(iv) *Poison Baits.*—The following poison baits were tested on 16th September on heavily-infested land carrying short, three years-old cocksfoot grass :—

1.	White Arsenic (80 per cent. As_2O_3)	1 lb.
	Bran	25 lb.
	Molasses	4 lb.
	Water	3 qrts.
2.	Paris green	1 lb.
	Bran	25 lb.
	Molasses	4 lb.
	Water	3 qrts.
3.	Paris green	$\frac{1}{2}$ lb.
	Bran	25 lb.
	Molasses	4 lb.
	Water	3 qrts.

The mash was distributed by hand at the rate of 75 lb. per acre of No. 1 and 150 lb. per acre of Nos. 2 and 3.

The plots were examined on 20th September and again on 2nd November. On the first date there was very little evidence of poisoning, but at the second examination plots treated with 2 and 3 were found to be very free from grubs, whilst 1 gave distinctly poor results. It should be noted that the quantities used per acre are greatly in excess of those found effective in the control of cutworms, grasshoppers, and other chewing insects.

In view of the great advantages of poison baits over sprays and dusts, it is very desirable that the possibilities of this method of control be thoroughly explored. It is very probable that there are cheaper and more attractive ingredients than bran and molasses and that much lighter applications of a suitable bait may be effective.

(v) *Cultural Methods.*—Harrowing and rolling suggest themselves as possible methods of control. Neither have been tested. The former method is not likely to be effective but experiments should be carried out between 14th April and 7th May, when the grubs are near the surface. Rolling appears to offer better prospects of success if carried out with a heavy roller between the dates mentioned above.

For obvious reasons, ploughing could be employed only in cases where it is intended to destroy the existing pasture. The best time for ploughing must be determined by the condition of the land and the use to which it is to be put. Only those crops that are not subject to attack, such as peas, rape, &c., could be safely sown immediately after autumn and winter, and, possibly, early spring fallowing.

The effect of ploughing on the egg and its subsequent development is not known. It is known, however, that young grubs when turned under by the plough in June may survive until the newly-sown crop (wheat) is sufficiently advanced to enable them to resume the normal surface feeding. It appears probable that other cereals or grass may be similarly attacked if sown on grub-infested land immediately after ploughing at any time from April to July; or possibly later, and until further investigations have been made it would be advisable to regard the best time for ploughing such land, if intended to be laid down again in pasture or under cereals, as from about the beginning of October to January, which period covers the latter stages of larval life and the pupal or chrysalis stage.

Late spring and summer ploughing is generally believed to be an effective means of destroying the mature or nearly mature grubs and the pupae. There is no evidence that the former ever migrate from recently fallowed grassland; but during these investigations moths were seen emerging from land that had been fallowed two months previously or after the grubs had ceased feeding. In this field the soil was very dry and loose and had been ploughed to a depth of 2½ in. to 3 in. In another field in which the soil was very stiff and clayey the emergences were confined to those moths that were able to leave the pupal case at the bottom of the furrow and make their way to the surface by means of crevices between the sods. Harrowing after ploughing would almost certainly have prevented the emergence of moths from either class of land. Whether these moths subsequently mated and oviposited on the fallowed land or whether they migrated to adjacent grassland could not be determined.

(vi) *Top Dressing.*—Top dressing with superphosphate is thought by some to have an insecticidal as well as a manurial value when applied to pastures. To test this point, a 1-acre block in Field 2 was top-dressed on 1st September at the rate of one bag (186 lb.) per acre, with apparently entirely negative results.

It was planned to carry out tests with mixtures of superphosphate and calcium arsenate, but as supplies were not available sufficiently early in the season they were deferred.

3. Moth Stage.

No economically possible method of controlling the pest in the moth stage suggests itself. Lamplight (acetylene) and flares of burning brushwood appeared to be repellent rather than attractive.

Calcium cyanide (Cyanogas " A " Dust) was found to be very effective on a small test plot when dusted over the pasture at the rate of 200–250 lb. per acre between the time of emergence from the pupae and commencement of the mating flight. Apart from the prohibitive cost of material, there are many obvious reasons for dismissing this method of control as practically and economically impossible.

4. General Conclusions.

1. The control of this pest in the egg and moth stages appears to be economically and practically impossible.

2. In the larval stage a fair degree of control (say 75 per cent.) is economically possible by means of arsenical sprays if the pasture is short and free from matted dead grass and other debris.

3. The cost of spraying, based on the following figures, viz. :—

	s.	d.
Hire of man and horse, per day	15	0
Hire of assistant, per day	10	0
Lead arsenate powder, at 1s. 6d. per lb., at rate of 4 lb. per 100 gals. water and 100 gals. per acre per acre	6	0
Petrol, at 2s. 3d. per gal., used at rate of 1 pint per 100 gals. .. .. per acre	0	3
Lubricating oil	0	3

is estimated at 9s. 1d., 8s. 5d., and 8s. 2d. per acre for 10, 14, and 16 acres per day respectively. An additional 2 lb. of arsenate per acre will give better control, say, 90 per cent., at a cost of 12s. 1d. per acre for 10 acres per day, with corresponding decreases for 14 and 16 acres per day.

4. Preliminary experiments indicate that dusting with calcium arsenate is not a practicable method of control, but further trials are desirable.

5. The results of trials with poison baits indicate the possibility of developing an effective and comparatively cheap means of control applicable to types of grazing land inaccessible to sprays.

6. Two important pests, which are often associated with *Oncopera*, namely, army worms and white grubs, can be controlled by arsenical sprays and dusts directed primarily against the principal pest.

IV. NATURAL CONTROL.

No fly or wasp parasites have been discovered during these investigations, nor can much be added to the information contained in Lea's handbook regarding other forms of natural control. The predaceous beetle *Promecoderus ovicollis* plays an important part, but it is not particularly abundant in the northern part of Tasmania. The small red ant referred to by Lea as an egg predator was not encountered, probably due to the fact that most of these investigations were carried out in sown pastures, where ants are never very abundant. Birds undoubtedly destroy an immense number of larvae, especially during showery weather, when they are near the entrance to the burrows or under the covered ways. Of the indigenous species, crows, crow-shrikes or magpies (*Strepera and Gymnorhina*), and spur-winged plovers are the most important in this connexion, but none of them compare with the introduced starling. Lea places the bandicoot first amongst the natural enemies of *Oncopera*, but unfortunately this animal appears to be comparatively scarce in the more closely-settled districts, although it is still an important factor in destroying the larval and moth stages. The latter are preyed upon to a small extent by crows, brown hawks, fan-tailed cuckoos, starlings, and domestic cats.

During seasons of exceptionally heavy rainfall countless thousands of grubs perish by drowning. In the Longford district, masses of dead grubs were seen floating downstream with driftwood and other flood debris; whilst at Cressy and near Hobart an incredible number were found in fields that had been submerged during the previous week. A mere surface film of water however, is not destructive to them since they are able to live for weeks in flooded burrows with only the head and thorax above water level.

Severe and continued frosts are popularly supposed to destroy *Oncopera* and army worm larvae, but these investigations showed that both pests are only temporarily affected by extreme cold.

A parasitic fungus apparently quite distinct from *Cordyceps gunnii*, Berk and *Isaria oncopterae* McAlp., the two species hitherto recorded as attacking *Oncopera*, was found commonly in the Scottsdale district from June to January. The smallest larvae found to have been destroyed by this organism were about ½ in. long; all subsequent stages and the pupae are similarly affected, indicating that its active period extends over a period of at least seven months. In some localities, only about 2 per cent. of the larvae dug up during one day were affected; in others the percentage rose to as high as 15 per cent.

V. OTHER PASTURE PESTS.

In the preceding pages, references have been made to two other insects which infest Tasmanian pasture lands, namely, army worms and white grubs, both of which cause very extensive damage and must be regarded as major pests. The life-history and habits of these insects are imperfectly known, but it is possible to give some hitherto unrecorded facts of practical value regarding them.

1. The Army Worm.

The army worm (*Persectania ewingi* Westw.). Periodic invasions of army worms have, unfortunately, made this insect only too well known to Tasmanian farmers. These invasions generally occur at intervals of several years, consequently farmers are taken unawares and generally lose heavily, as in the early summer of 1926. In seasons of normal abundance, this insect passes almost unnoticed, and its depredations are confused with those of *Oncopera*, with which it is commonly associated. On 31st January of last year, Field 2 showed unmistakable evidence of having been heavily infested with these caterpillars. The surface soil and short tussocky grass was littered with their excrement and almost every head of cocksfoot had been nipped off near the seed head, whilst dead and shrivelled caterpillars, victims of an epidemic, were to be seen in all directions. Full-grown larvae and recently transformed pupae were found in great numbers in the loose dry soil and ashes at the butt of a burnt-out tree, under the shelter of cow-dung and chips, and in the surface soil on the sheltered side of logs and fence-posts. A large proportion of the larvae was parasitized by an unidentified species of Tachinid fly, which emerged from 5th to 7th March, and from the pupae moths emerged from 22nd to 26th February. These moths (the summer brood) were doubtless the progenitors of the larvae which were found abundantly in tussocks of grass during the following winter and of the moths (spring brood) which emerged in the latter part of September. From May onwards through the winter, and apparently until pupation takes place in the early spring, the larvae live in the tussocks and in burrows from 1 to 3 inches deep, which open out on the surface to a short silk-covered runway from which they attack the adjacent foliage. The burrows are neither as deep nor as well formed as those of *Oncopera*, and differ from the latter in always containing a mass of excrement at the bottom. In badly-infested pastures, the damage caused by these caterpillars is very considerable, and for the first few months of winter sometimes exceeds that of *Oncopera;* the latter, however, have a much longer larval stage and, although only single brooded, ultimately outrival the army worm in destructiveness in seasons of normal abundance, not only by devouring more foliage, but by causing permanent injury or total loss of the plants attacked.

The habits of army worms expose them to destruction by several important natural enemies, in addition to the Tachinid flies and epidemics mentioned above. The most important of these enemies are starlings and a common reddish-coloured ichneumon-fly (*Henicospilus* sp.). To what extent the former prey upon the army worm may be indicated by the fact that from five to sixteen quarter to half-grown larvae were found in each of eighteen birds examined in July.

Because of its habit of feeding very largely upon the exposed parts of grass plants, the army worm is much more susceptible to arsenical sprays than is *Oncopera*, and in all the experimental blocks 3 lb. (powder) and upwards per 100 gals. of water gave satisfactory results.

2. White Grubs (various species).

Several species of white grubs—the larvae of cockchafer (*Scarabaeidae*) beetles—are found more or less abundantly in Tasmanian grasslands. Lea (1908) mentions *Anodontonyx nigrolineata* Bir. (*Scitala languida* Er.) as being the most destructive species and has, in addition, identified the adult stage of *Scitala sericans* Er., *Heteronyx tasmanicus* Bl. and *Aphodius howitti* Hope from material collected during these investigations

The larvae of the various species have not been studied in sufficient detail to enable them to be identified with certainty, but, so far as the Scottsdale district is concerned, it can be said that one species is of outstanding importance, although it is possible that some of the others are more abundant than these investigations have so far indicated. The identity of this insect has not yet been definitely established, but there is some reason for believing that it is the larval stage of the beetle *Aphodius howitti* Hope, which has not hitherto been recorded as a pest, though it is well known as a common dung beetle. This species appears to require about two years in which to complete its larval development, during the greater part of which it lives a free existence in the soil, feeding upon the roots of grasses and clovers. After a moult in May, it appears as a whitish, curved grub with large dark brown head and yellowish mouth parts and, abandoning its earlier habits, constructs a burrow from which it emerges at night to feed.

In constructing these burrows the soil is thrown up loosely until in June in heavily-infested ground the whole surface and small plants are more or less covered with soil to a depth of an inch or more. The burrows are from 3 in. to 4 in. deep and about $\frac{1}{4}$ in. in diameter, with a sloping runway leading out on to the surface. The runway and entrance are generally closed by day with loose soil, which is cleared away at night to enable the grub to reach its food plants. The vertical portion contains a single grub resting upon or in a mass of freshly-gathered foliage, comprising the leaves and stems of the various clovers and of cocksfoot and rye grasses. About the middle of September, many of the grubs were found to have reached maturity and to have entered upon a prepupal stage of undetermined duration in rough cells at the bottom of their burrows, where pupation subsequently takes place. A few late developing individuals continue to feed until late in December, when the first pupae were found. In light volcanic soils as many as 40 grubs were collected in an area 12 in. square, whilst upwards of 50 were gathered under a piece of cow-dung; fortunately most of the pastures are less heavily infested or almost entirely free of the pest. The first beetles were seen early in January, during which month and the first week of the following month they were only moderately plentiful, suggesting that the majority had already emerged.

Owners of the most heavily infested of the pastures examined stated that it is only within recent years that the white grub has become prominent as a pest in this district, and that its advent had rendered almost impossible the establishment of clovers in some of their mixed pastures and the maintenance of these fodders in pastures already denuded of useful grasses by *Oncopera*. The history of a 12-acre block on this property—some of the richest volcanic soil in north-east Tasmania—indicates to what extent first-class land may be reduced in value by the combined ravages of *Oncopera* and white grubs. After many years of cultivation, this paddock was ploughed and sown in the autumn of 1923 with oats, annual and perennial clovers and cocksfoot; seven months later 27 head of large stock were turned into it and remained there continuously for six weeks, when, following a five weeks' "spell," it yielded $2\frac{1}{2}$ tons (dry weight) per acre of fodder. With the harvesting of the annual plants, the paddock was considered to be an established permanent clover and cocksfoot pasture, and as such should have been a profitable investment until, by the system of rotation followed, it was required for other purposes. During the following summer (1924), it became infested with *Oncopera*, which by the end of 1925 had practically eliminated the cocksfoot, leaving little more than the perennial clovers, which alone were considered sufficiently profitable to justify the retention of the area for grazing purposes. White grubs, however, made their appearance in the autumn of 1926 and by the following October had left nothing of any value as fodder.

(*i*) *Natural Enemies.*—No fungus or insect parasites of white grubs were observed on these pastures, and it is doubtful if many of them are destroyed in their earlier stages by birds and other animals; but from the time the burrows are commenced they are constantly preyed upon by starlings, and to some extent by magpies and crows, to whom they are generally accessible, due to the fact that the stores of green-stuff in the burrows compel the insects to frequently rest near the surface.

(*ii*) *Artificial methods of control.*—The surface-feeding habits of the older stages of this grub, which appear to be unusual in allied pests, render them susceptible to the effects of poisonous sprays and dusts, and in all the tests made on *Oncopera* with lead arsenate (3 lb. and upwards per 100 gals. of water) and calcium arsenate dust the control was almost complete.

The best time for either spraying or dusting would be the latter part of June or early July; if delayed until September or October much damage to the herbage would have resulted from their prolonged attacks. If, however, the pastures are heavily infested with *Oncopera* and army worms, as most probably would be the case, it might be more profitable to delay treatment for a few weeks with the object of destroying all three pests at one operation.

VI. ACKNOWLEDGMENTS.

The writer extends very cordial thanks to those who have assisted in these investigations. This assistance has been given most willingly by officials of the Department of Agriculture, by graziers and agriculturists, by residents and by fellow entomologists, and has included facilities for travel, the use of farm stock and equipment, labour, expert advice, and hospitality. The co-operation of Messrs. P. E. Keam, H. G. Salier, H. Briggs and Sons, to mention only a few individually, has been enlisted on numerous occasions, and has been indispensable. The coloured frontspiece is the work of Mrs. Mavis Arnold, B.Sc., to whom thanks are due also.

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VIII.—APPENDIX.

During the progress of the foregoing report through the press, a further series of experiments for the control of the grub stage of *Oncopera* was carried out in the Scottsdale district between the 31st August and 14th September, 1928, details and results of which are recorded hereunder. Brief references are made also to the progress of investigations elsewhere and to Tasmanian pastures.

1. Field Experiments.

(i) *Spraying.*

The equipment used in spraying was the same as that employed in the earlier experiments (see p. 18), with the exception of the substitution of two E.C. Brown strainer nozzles for an equal number of Friend nozzles on the spray boom. The former pattern proved to be more satisfactory than the latter, inasmuch that there were no stoppages due to the clogging of nozzles. The fluid was distributed at the rate of about 90–100 gallons per acre at pressures ranging from 200 lb. to 250 lb. per inch.

(*a*) *Lead Arsenate.*—Approximately 4 acres in Field 2 (see p. 19) were sprayed on 3rd and 5th September with a well-known commercial brand of lead arsenate (powder) in solutions of 3 lb., 4 lb., 5 lb., 6 lb., and 7 lb. per 100 gallons of water. The pasture was short, dense, and almost free from weeds, dry grass and other obstacles to successful spraying : young clover was much in evidence, and the general condition of the field had improved very markedly since the beginning of the year. *Oncopera* grubs were moderately numerous throughout, and on one block, which had been used as a control for previous experiments and had received no previous treatment whatever, were exceedingly numerous on all parts not affected by storm water from an adjacent road. Army worms and white grubs were present in negligible numbers on all blocks.

Four blocks, each of ½ acre, were sprayed on 3rd September with solutions of 3 lb., 4 lb., 5 lb., and 6 lb. per 100 gallons, and two blocks each of 1 acre were sprayed two days later with solutions of 4 lb. and 7 lb. per 100 gallons. For several weeks previously the weather had been very cold and windy, with frequent heavy showers of rain, but from noon on 1st to 7.30 p.m. on the 4th there had been no rain and the conditions on the 3rd were nearly perfect for spraying operations. Heavy showers fell at intervals throughout the night of the 4th, but on the following afternoon it was possible to spray the two larger blocks under favorable conditions, although heavy rain fell at intervals for a few hours during the evening after most of the spray had dried on the foliage. Following these showers there was no further rain until the morning of the 9th, when there commenced a period of five days of frequent and prolonged heavy falls.

In each of the four smaller blocks, small areas of infested pasture were covered in various ways immediately after spraying to protect them from the effects of rain. In some of these small areas the covered ways over the burrows were removed so as to expose the entrance to the latter and the damaged butts of the tussocks to the full effect of the spray. (This procedure was adopted also in experiments with calcium arsenate, Paris green, sodium arsenate, and poison baits.)

On the 11th September, eight days after spraying, the grubs (25 in number) in the small protected areas were removed from their burrows and examined for evidence of poisoning; none appeared to be affected. This result was most unexpected in view of the fact that the exposed feeding surface had been thoroughly wetted by the sprays used and that sprays of similar strengths had given definite results on the third and fourth days in the series of experiments carried out twelve months earlier (p. 21).

On the 25th October all six blocks were re-examined, when it was found that there had been an almost complete destruction of grubs with solutions of 5 lb., 6 lb., and 7 lb. per 100 gallons, and only slightly less satisfactory results with 4 lb.-100 gallons. On the block previously referred to as being most heavily infested, which was sprayed with 3 lb. per 100 gallons, there was still present a destructive number of grubs in places, but over the greater part of it they were not sufficiently numerous to cause appreciable damage. The present condition of this field, including two ½-acre blocks (to be referred to later) which were sprayed with Paris green, is in striking contrast to its condition in the spring of 1926 and 1927. The whole area (with the exception noted above), formerly heavily grub-infested, and showing more or less extensive bare patches, is now a continuous sward of grass and clover, with a grub-population over the greater part of it of one per 10 to 12 square yards.

(*b*) *Paris green.*—Two ½-acre blocks in Field 2 were sprayed with Paris green, 4 lb. per 100 gallons and 2 lb. per 100 gallons, on 31st August and 3rd September respectively. Rain fell during the night of 31st August and morning of 1st September, necessitating the re-spraying of one of the blocks on 3rd September. As previously noted, no rain fell on the night of the 3rd, but there were heavy showers during the following night. On the 11th there was evidence of foliage burning with the stronger solution, particularly along wheel tracks; but the amount of damage to forage plants was negligible. On this date many grubs were gathered from the protected areas and other parts of the pasture, none of which appeared to be affected by poison. These two blocks were again inspected on 25th October, when they were found to be almost grub-free.

(*c*) *Calcium Arsenate.*—A ¼-acre block of very heavily infested land, from which nearly all useful herbage had been eliminated by grubs during preceding years, was sprayed on 6th September with calcium arsenate at the rate of 8 lb. (powder) to 100 gallons water. From the time of spraying until the morning of the 9th no rain fell; there were, therefore, three nights available for the ingestion of the heavily sprayed foliage before rain could influence the results. On the 11th some of the grubs appeared to be affected by poison, and there was a negligible amount of burning of clover foliage. Slugs, which were exceedingly plentiful in this field, appeared to be unaffected. On 25th October, when the block was next examined, it was estimated that only 60 per cent. to 70 per cent. of the grubs had been destroyed. The effect, if any, upon slugs could not be determined.

(*d*) *Sodium Arsenite.*—In view of results obtained elsewhere it appeared desirable to test sodium arsenite as a combined weed-killer and insecticide. For this purpose an unstocked field, which had ceased to be productive (as a result of grub infestation) and which was about to be fallowed, was selected. The herbage comprised a small quantity of worthless grass (fog and silver-grass), thistles, dandelions, sorrel, and scattered plants of clover and trefoil. *Oncopera* grubs and slugs were exceedingly plentiful, while several species of cutworms and army worms were present in small numbers. The poison used was sodium arsenite (containing 80 per cent. As_2O_3) in the form commonly retailed as "weed killer." Solutions containing 4 lb., 6 lb., 8 lb., and 16 lb. of the poison to 100 gallons water were used at the rate of about 100 gallons per acre on ½-acre blocks.

Solutions of 8 lb. and 16 lb. per 100 gallons were applied early in the afternoon of 4th September. Heavy showers fell between 7.30 and 8.30 p.m. and again on the following night. On the morning of 5th September dead slugs were to be found in considerable numbers on both blocks. On the following morning (6th) the eradication of slugs appeared to be complete, whilst dead cutworms, army worms and another grass-eating caterpillar (*Anthela*) were to be found in considerable numbers. Neither in the covered nor open areas were there any indications that *Oncopera* larvae had been affected. At 3 p.m. thistles, sorrel and dandelion showed evidence of severe burning, trefoil and clover were slightly affected, and grasses unharmed. On the 7th *Oncopera* appeared to be still unaffected. On the 11th, when the next examination was made, dead and dying *Oncopera* were found in both blocks, either on the surface or with the head visible at the entrance of the burrows. On this date, the various weeds previously mentioned showed extensive burning, whilst trefoil was severely burnt. Clover was hardly affected at all and was making new growth. Of the two grasses only silver-grass was affected. In all cases the damage along wheel tracks was so great that the latter were conspicuous at a considerable distance. When the final examination was made on 25th October both solutions (8 lb. per 100 gallons and 16 lb. per 100 gallons) appeared to have reduced *Oncopera* by about 75 per cent. to 80 per cent. The effect on weeds was most marked where the stronger solution had been used, but in neither block had the weeds sustained more than a severe check. There were no appreciable ill-effects on trefoil and clover.

Solutions of 4 lb., 6 lb., and 8 lb. per 100 gallons were applied about noon on the 6th September under similar conditions to those noted above. Following the application of the spray, there was a period of 60 hours during which no rain fell to affect the poison ; there were thus three nights available for feeding under conditions favorable to a satisfactory degree of control. At 3 p.m. on the 7th slight burning of susceptible foliage was noticed, but there was no indication that *Oncopera* was affected. On the 11th the condition of the herbage and the grubs on the block sprayed with 8 lb. per 100 gallons was similar to that recorded for the same date in the case of the block sprayed on the 3rd with the same solution. Similar foliage burning occurred also in the block sprayed with 6 lb. to 100 gallons, but there were markedly fewer dead and dying grubs. Four lb. per 100 gallons caused extensive foliage burning to susceptible weeds, but had no effect on fog-grass, clover, and trefoil, whilst its effects on *Oncopera* larvae was perceptibly less pronounced than were those of the stronger solutions. Unfortunately these two latter blocks were fallowed before further data could be obtained. On 25th October no appreciable difference could be detected between the condition as regards both foliage-burning and grub population, of the blocks sprayed with 8 lb. per 100 gallons on 3rd and 6th September respectively, notwithstanding the fact that in the first trial spraying operations were followed a few hours later, and again on the following night, by heavy rain, whereas in the later trial there was a rainless period of 60 hours.

(ii) *Rolling.*

Trials made on 3rd May with an ordinary field roller on a 1-acre block in Field 2 indicate that this method is not likely to prove of practical value in the control of *Oncopera*. In exceptional circumstances, i.e., when the surface is well graded and free of obstructions and debris and the contour of the land such that a heavily-loaded implement could be employed, it is possible that more satisfactory results might be obtained. Such conditions, however, are seldom to be found in Tasmania.

(iii) *Dusting.*

Attempts were made to carry out further trials with calcium arsenate dust as a means of controlling *Oncopera*; but, after repeated failures, due to adverse weather conditions, these were abandoned. Apart altogether from considerations of cost and effectiveness, it would seem that meteorological factors alone render it extremely doubtful if dusting could be employed against this pest.

(iv) *Poison Baits.*

The following poison baits were tested on 7th September on five blocks each measuring 7 yds. by 27½ yds. :—

(1)	Paris green	½ lb.
	Bran	25 lb.
	Water	3 qts.
(2)	Paris green	1 lb.
	Bran	25 lb.
	Molasses	64 fluid oz.
	Water	3 qts.
(3)	White arsenic (80 per cent. As_2O_3)	1 lb.
	Bran	25 lb.
	Molasses	64 fluid oz.
	Water	3 qts.
(4)	Calcium arsenate	1 lb.
	Bran	25 lb.
	Molasses	64 fluid oz.
	Salt	2½ lb.
	Water	3 qts.
(5)	Sodium fluoride	1 lb.
	Bran	25 lb.
	Molasses	64 fluid oz.
	Water	3 qts.

The blocks were a continuation of, and in the same condition as, those sprayed with sodium arsenate. The mash was distributed by hand at the rate of 78 lb. per acre of No. 1 and 39 lb. per acre of Nos. 2–5. In each block a few small particularly heavily-infested areas were isolated within suitably covered metal collars which confined the larvae to definite feeding grounds from which rain was excluded, whilst others were very heavily baited and left unprotected from the elements. Distribution was made during the evening of 7th September, and as no rain fell during the following 36 hours, two fine nights were available for feeding before the toxicity of the exposed baits could have been affected.

On 11th September, one dead and four living *Oncopera* were found in each of two exposed areas which had been heavily baited with Nos. 1 and 2, whilst three dead and five living *Oncopera* and three dead cutworms found in one similarly treated with No. 5. There was no mortality with Nos. 3 and 4.

On 13th September the following data were noted from the protected areas :—

—	Unaffected.	Affected.	Dead.	Total.
No. 1 (*a*)	1	3	4	8
(*b*)	2	1	3	6
(*c*)	4	1	3	8
No. 2 (*a*)	2	2	3	7
(*b*)	1	1	1	3
(*c*)	1	2	3	6
No. 3 (*a*)	1	1	2	4
(*b*)	2	1	3	6
No. 4 (*a*)	7	..	1	8
(*b*)	5	..	1	6
No. 5 (*a*)	..	..	3	3
(*b*)	..	..	5	5
(*c*)	..	..	4	4

On the last-mentioned date only a few dead and affected larvae were found on each of the main blocks. A small proportion of the burrows had been vacated, indicating that their former occupants had been affected by poison and made their way to the surface, probably to be gathered by birds.

On 15th September, five blocks adjoining the above and similar in area and condition were poisoned with baits Nos. 1-5 respectively, the quantities used being the same as before. No records were kept of the weather conditions subsequent to the distribution of the material.

On 25th October all of the blocks were found to be still very heavily infested, the control being practically negligible. Of the five baits used, sodium fluoride (No. 5) alone gave any appreciable result, and in this case it was estimated that less than 25 per cent. of the grubs had been destroyed.

(v) *Top-dressing.*

(*a*) *Superphosphate.*—On 3rd May further trials were made on two 1-acre blocks in Field 2 to determine the larvicidal properties of superphosphate when applied as a pasture fertilizer in the usual quantity (186 lb. per acre) and manner. The results, noted in the following October, appeared to be entirely negative, as in the case of the first experiment (September, 1927).

(*b*) *Lime.*—A ½-acre block in Field 2 was top-dressed with 2½ cwt. of lime on 3rd May. In October it was evident that the treatment had been ineffective, even in isolated places where the quantity deposited had been sufficient to completely cover the burrows to a depth of from ¼ inch to ½ inch.

(*c*) *Superphosphate—Arsenic.*—Twelve 7-lb. samples of H.G. super., containing respectively 5 per cent., 10 per cent., 20 per cent., 30 per cent., 40 per cent. and 50 per cent. calcium arsenate (samples A1-A6) and 2·5 per cent., 5 per cent., 10 per cent., 15 per cent., 20 per cent., and 25 per cent. arsenic trioxide (samples B1-6) were courteously supplied by the Electrolytic Zinc Co. Ltd., Risdon, Tasmania, and tested as a combined fertilizer and larvicide on moderately heavily-infested pasture in which trefoil predominated. The various mixtures were distributed by hand at the rate of 186 lb. per acre during brief intervals of calm and fine weather. Following a few hours after the distribution of sample A1-A5 on 4th September, and A6, and B1–4 on 5th September, there was heavy rain which removed most of the material from the foliage. Samples B5 and 6 were distributed on 7th September, and were not subjected to the action of rain until two days later.

On 11th September, when the first examination was made, one dead grub was found on the surface of block treated with A5; whilst on blocks treated with A1 and A2 there was evidence of foliage burning on thistles and other weeds. On 25th October, when the second examination was made, a very marked improvement in the herbage on all blocks was noted, due almost entirely, it appeared, to the action of the fertilizer. The trefoil, formerly stunted and more or less dormant, had become a dense mat in which *Oncopera* burrows were difficult to locate. In blocks treated with A1-3 and B1–3 the destruction of grubs was negligible; in the remaining blocks the control showed progressive improvement as the percentage of arsenic increased, but in none were the results at all satisfactory. Comparisons between blocks treated with A6 and B6 with their controls showed a reduction in grub population of only 31 per cent. and 24 per cent. respectively. These figures, however, are only approximate, since it was impossible to determine the population of the several blocks before the experiments were commenced.

(vi) *Conclusions.*

1. The results of the spraying experiments outlined in the Appendix confirm conclusions 2, 3, and 4 (p. 25) previously arrived at.

2. Lead arsenate (5 lb. to 6 lb. (powder) per 100 gallons of water) is the most satisfactory of the various sprays tested.

3. Spraying is likely to be most effective if carried out during the latter part of July to the early part of September.

4. Dusting, rolling, the use of poison baits and top-dressing have proved unsatisfactory for the control of *Oncopera*.

2. *Other Investigations.*

(i) *Investigations in Victoria.*—Further investigations in this State have failed to demonstrate the existence of parasites other than those previously referred to (p. 6).

Porina fuscomaculata, the life-history and habits of which are very imperfectly known, has been found recently in abundance in a Gippsland pasture, where it was causing damage to introduced fodder grasses hardly less serious than that observed in *Oncopera*-infested pastures in Tasmania. It would appear from these investigations that the larval stage of this insect requires a much longer period for its completion than is the case with *Oncopera*, but in certain stages in their development and in their habits they so closely resemble *Oncopera* that they cannot be excluded from this research.

(ii) *Investigations in England.*—Arrangements have been made for an investigation to be undertaken in England on the life-history of *Allomyia debillator* Fabr. the ichneumon-fly parasite of *Hepialus humuli* referred to on page 6.

(iii) *Taxonomic Work.*—The investigation of the *Oncopera* problem in Tasmania has led inevitably to a study of certain allied mainland species which have received, or are receiving, the attention of specialists. In order to avoid overlapping and resulting confusion, it has been deemed advisable to secure the collaboration of a lepidopterist with an expert knowledge of this group of insects and with access to material not available to the writer. Arrangements have been made accordingly, with the approval of the authorities of the South Australian Museum, for the co-operation of Mr. N. B. Tindale in the preparation of a paper dealing with aspects of the research of no immediate interest to the Tasmanian grazier.

3. *Tasmanian Pastures.*

The possibilities of controlling *Oncopera* in Tasmanian grass-lands by artificial and biological methods have been discussed in the preceding pages ; there remains to be considered the question of introducing other varieties of fodder plants and a system of shorter rotation of crops. The writer's enquiries amongst farmers indicate that there are practical difficulties to be overcome in both directions ; these matters, however, are receiving the attention of the experts of the State Department of Agriculture, whose objective is not only an improvement in the fertility of arable land, but the elimination of the present waste due to the depredations of *Oncopera*. Since the most serious loss due to the latter generally occurs during the third and fourth years, it is obvious that any system of rotation which will reduce the period during which the land is under grass must have a very important result in relation to the pests referred to in this report. It is of interest to note in this connexion that cow-grass clover is reported to have been seriously damaged by these grubs in the Ringarooma district during the second year of its growth.

EXPLANATION OF PLATES.

Plate 1.

Fig. 1.—Tasmanian Grass-grub (*Oncopera intricata*, Walker).

Fig. 2.—Pupa.

Fig. 3.—Moth.

Fig. 4.—Moth, with wings expanded.

Plate 2.

Fig. 5.—Grub-infested cocksfoot before removal of covered ways; also showing spray residue.

Fig. 6.—The above after removal of covered ways; showing entrances to five burrows and damage to crown of plant.

Plate 3.

Fig. 7.—Grub-infested cocksfoot before removal of covered ways.

Fig. 8.—The above after removal of covered ways; showing entrances to five burrows and damage to crown of plant.

Plate 4.

Fig. 9.—Section through cocksfoot plant, covered way and burrow; showing destruction of butt and silk-lined burrow.

Fig. 10.—Grub-infested four-years old pasture (Field 2); note destruction of grass below and to left of sheep.

Plate 5.

Fig. 11.—Close view, showing grub-holes after sweeping away surface coverings (Field 2).

Fig. 12.—Rougher type of pasture (Field 3).

Plate 6.

Fig. 13.—Hilly grazing land; Field 2 in top left corner, bracken-covered field in centre; ferns in paddock on left have been recently cut.

Fig. 14.—Spraying outfit.

PLATE 2.

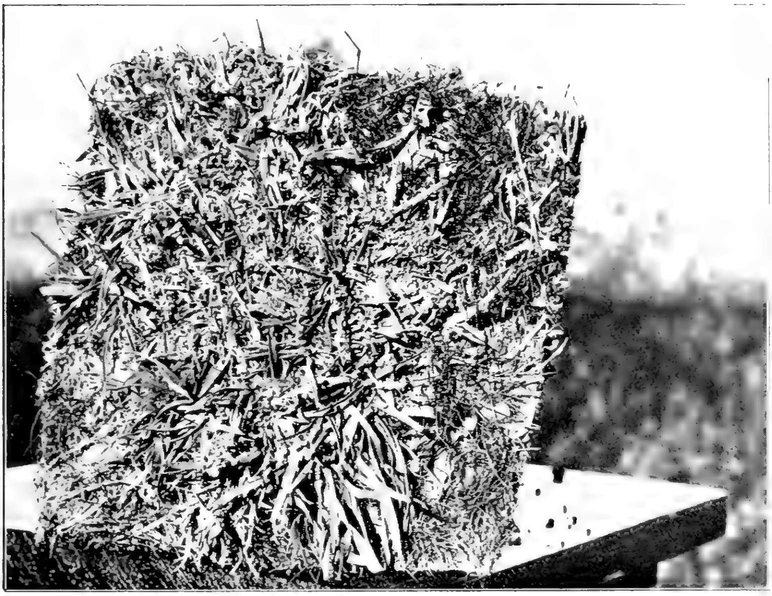


Fig. 5.—Grub-infested cocksfoot before removal of covered ways; also showing spray residue.

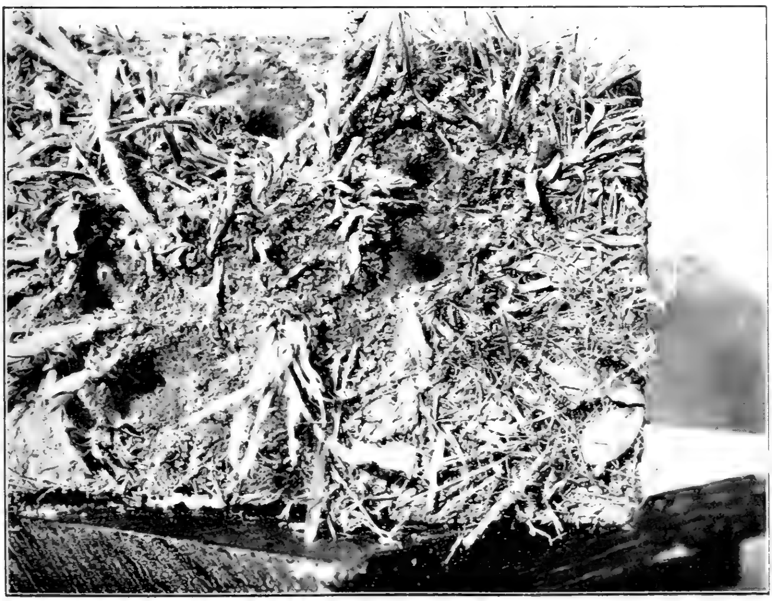
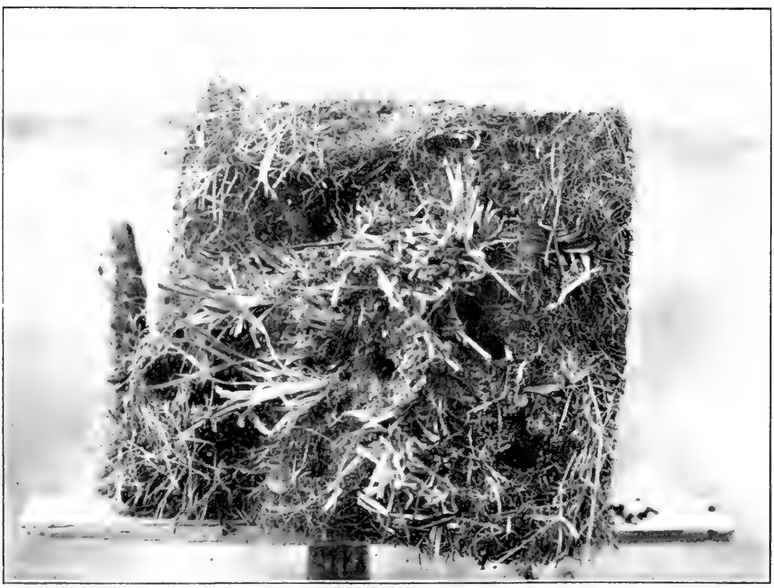


Fig. 6.—The above after removal of covered ways, showing entrances to five burrows and damage to crown of plant.

PLATE 3.

FIG. 7.—Grub-infested cocksfoot before removal of covered ways.



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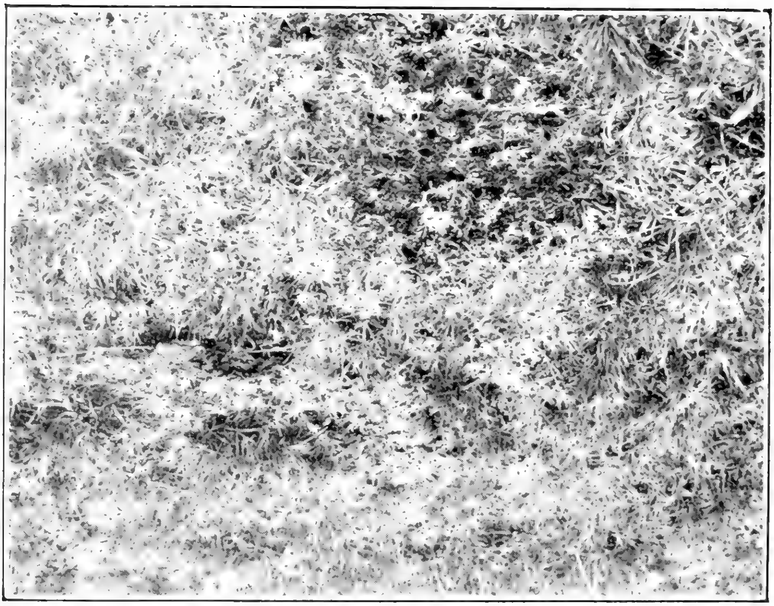

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PAMPHLET No. 12

COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

THE

CATTLE TICK PEST

AND

Methods for its Eradication

MELBOURNE, 1929

By Authority:
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C.11071.

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PREFATORY NOTE.

This pamphlet is a report prepared for publication by the Cattle Tick Dip Committee, which has for some years been carrying out a programme of investigation in Queensland. The necessary funds are contributed by the Departments of Agriculture of New South Wales and Queensland and by the Council. The Committee is composed of representatives of the contributing organizations. Its personnel at the time this report was prepared is given on page 17.

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THE CATTLE TICK PEST

AND

METHODS FOR ITS ERADICATION.

I. INTRODUCTION.

The eradication of the cattle tick from Australian herds is a problem which is of vital concern to the welfare of the pastoral and dairying industries of the Commonwealth. To place these industries on a scientific and profitable basis the minimization of the tick is essential, and its elimination is greatly to be desired.

Although the stock owners and dairymen will obtain the greatest advantage from the results of a campaign for tick eradication, the benefits to be derived in other directions, such as in the tanning and leather industries, make the problem one of national importance.

This pamphlet contains a summary of the latest information on the cattle tick and the methods by which it can be eradicated. It contains the essential features of the previous Bulletins (1) and (13),* and, in addition, the results of further scientific investigations carried out in pursuance of the policy originally outlined by a special Committee appointed by the former Institute of Science and Industry in 1917. The recommendation of that Committee was as follows :—

> That further scientific investigations should be carried out on the life history of the cattle tick in Australia, the micro-organism conveyed by the tick which causes tick fever, methods of treatment of cattle, and improvement of tick destroying agents.

A Cattle Tick Dip Committee was appointed in 1918 to carry out the proposals outlined above and, *inter alia,* to ascertain and collate scientific data in respect of dipping fluids, their potency in relation to the destruction of tick life, and the effect of dipping upon treated animals.

The activities of the Council for Scientific and Industrial Research in relation to the cattle tick are primarily centred at present in the operations of the Tick Dip Committee. The investigations of this body are outlined in the pamphlet.

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* Issued by the former Institute of Science and Industry.

II. THE CATTLE TICK PEST.

Owing to the serious losses it occasions, the extent of its incursion, and the persistent manner in which it spreads, the cattle tick pest constitutes an ever increasing danger to the bovine herds of the Commonwealth, and a grave menace to many important industries.

The incidence of the pest causes two distinct disease conditions in cattle, viz., tick infestation and tick fever. The former may occur alone, but the latter under natural conditions is dependent upon the presence of infected ticks.

The fact that the cattle tick is capable of giving rise to disease *per se*, by gross infestation, has not always been recognized, and early records of the pest refer almost exclusively to tick fever or its synonyms.

Tick fever belongs to the class of diseases known as piroplasmoses, which are caused by endo-corpuscular parasites belonging to the group Protozoa. Many diseases which are now classified as piroplasmoses are known to have existed for centuries and to have a wide geographical range. The particular form of piroplasmosis known as tick fever in Australia is due to *Piroplasma* (*Babesia*) *bigeminum*, which is also the cause of Texas fever in the United States of America, and similar diseases in Europe, Asia, South America, and South Africa.

(1) Life-History of the Cattle Tick.

The Australian cattle tick (*Boophilus Australis*) differs in slight structural features from the "Texas fever" tick (*Boophilus annulatus*) of the United States of America, but the life-history and habits of the two are practically identical.

When the female tick becomes fully matured, she detaches herself from her host and falling to the ground preferably seeks some secluded spot, where she remains quiet for a period of from two to ten days in summer, or from two to three weeks, or even much longer, in winter; after which she commences to lay eggs. The number laid varies from about 1,500 to 3,000, the average being about 2,500. Those which hatch out vary from 3 to 98 per cent. Partially engorged females also lay viable eggs, but in smaller numbers. The eggs appear as dark reddish-brown ovoid wax-like bodies, about one-fiftieth of an inch long, and one-sixty-sixth of an inch broad at their widest part, and they are very resistant to changes in temperature. Moisture has but little effect upon them, consequently the spread of ticks by heavy rains washing the eggs from one pasture to another frequently occurs. Protracted exposure to direct sunlight destroys their fertility, although they may retain their viability for over eight months in creek flotsam. They are capable of withstanding the effects of low temperature (even 15° F.) to a remarkable extent. Under favorable conditions, the eggs proceed to develop larval or "seed" ticks, the time required for which varies from a fortnight to three weeks or more, depending upon external influences, such as temperature, moisture, shade, &c. Warm moist weather, such as that existing in our coastal areas, is most conducive to speedy hatching.

Since each female tick lays an enormous mass of eggs at one spot, thousands of larvae appear in the course of time at the same place, ascend the vegetation, fencing, &c., and collect in masses ready to swarm upon any object that brushes past. They do not appear to display any discernment as to the object to which they attach themselves, as is evident by their swarming on inanimate articles, such as clothing, blankets, &c. Their parasitism is, however, so perfect that, unless they attach themselves to a suitable host, no further development occurs; they soon fall off and in time perish. They are very tenacious of life and have been known to live for nearly eight months during the colder part of the year in America.

The larval tick, having gained its host, crawls over the skin and finally attaches itself by means of its mouth parts, preferably to places where the skin is soft, and at once commences its parasitic life by obtaining nourishment from the blood of its host. If infected with the pathogenic micro-organism it may cause fever, although it is so small as to be difficult to detect with the unaided eye. After being on its host for about a week, the six-legged larval tick casts its coat and emerges as an eight-legged nymph. It fastens itself close to the spot where it was previously attached, commences to grow, and becomes of a russet-brown colour with markings along the back. During the nymphal stage, the sexual organs develop, and at the second moulting in about another week, they are complete. The sexually mature female tick re-attaches herself on or near her original site, soon becomes fertilized by the wandering male, and rapidly increases in size until she becomes fully matured, when she is about half-an-inch long. At first she is of a slate grey colour, with a few irregular yellow markings and white legs, but becomes darker, longer and rounder as she distends her body with blood, a day or two before she drops off her host. The different periods occupied by the tick in its metamorphoses are subject to variations depending chiefly on meteorological influences and environment. Experiments made at Rockhampton by Tidswell in summer months indicate that the non-parasitic stage extended on the average to 23 days, and that the parasitic stage was fairly consistently about 21 days.

The cattle tick is the natural intermediary in the dissemination of tick fever, and it is probable that a single infected tick is capable of reproducing the disease in a susceptible beast. The transmission of the disease usually occurs soon after the larval tick attaches itself to the skin of the host, the infection being transmitted to the larval tick from the infected adult female parent through the egg. Non-infected ticks become infected when they feed upon an animal that harbours the piroplasma in its blood stream. Consequently those ticks which develop upon cattle that have not suffered tick fever, or upon other animals naturally insusceptible to the fever, are incapable of spreading infection. This fact accounts for the absence of tick fever in certain centres where the tick has been introduced by horses or sheep.

Adult ticks have been found on the face and legs of sheep in Queensland. It is generally considered that the tick would not develop where yolk exists on the skin, but Pound states he has found cattle ticks maturing in places where the wool was dense. Matured female ticks developing upon horses and sheep lay fertile eggs.

(2) Influence of Climate on the Activity of the Cattle Tick.

Although cattle tick infestation is practically confined to areas in Queensland, New South Wales, Northern Territory, and Western Australia within an average of 200 miles from the coast line, and only sporadic outbreaks have been noted and dealt with in the inland portions of Queensland, Western Australia and the Territory, it would be incorrect to say that cattle ticks will not live in the latter areas. They certainly do not flourish in those areas during a prolonged spell of dry weather when there is an absence of suitable vegetation necessary for protecting the engorged female ticks during oviposition and hatching of the eggs, but in an abnormally wet season, when heavy rains have been widespread, conditions are temporarily favorable for the unimpeded development of cattle ticks in localities in which they would not survive in normal seasons.

(3) Media for the Spread of the Cattle Tick.

Cattle are the natural hosts of the tick, and whilst horses and sheep are hosts in a lesser degree, their presence has not proved a serious obstacle to practical eradication work. At the Yeerongpilly Experiment Station, Queensland, which was stocked with horses and sheep as well as cattle, ticks were completely eradicated by the regular treatment of the cattle only, the horses and sheep being untreated. Nevertheless, where complete eradication is being undertaken the horse must be regarded as a potential source of danger and necessary precautions taken to deal with it. Especially is this necessary in the case of horses moving from tick-infested country to clean country or from infested to clean areas.

All experiments, both in Australia and in America, to induce cattle ticks to mature on dogs, cats, guinea pigs, rabbits and native wild animals and birds have been unsuccessful. In Australia, it has been shown that by regular and systematic dipping of cattle in standard arsenical solution, ticks have been eradicated in several districts where marsupials and other wild animals and birds are known to exist. During the visit of a representative of the Queensland Department of Agriculture and Stock to America in 1912, he personally observed in the tick infested areas in the southern States, numbers of wild animals including native jack rabbits, imported English wild rabbits, coyotes, prairie dogs, squirrels, opossums and numerous small animals, also a large variety of wild birds. Notwithstanding the unrestricted movements of these wild animals and birds, thousands of square miles of country, including entire States, have since his visit been completely freed from cattle ticks and released from quarantine restrictions. In the voluminous literature published by the Federal and State Governments in the United States dealing with practical tick eradication, it is significant that no mention is made of wild animals proving a hindrance to the work.

In portions of South Africa where similar conditions prevail regarding the presence of numerous wild animals and birds, successful eradication has been accomplished, although the matter was further complicated by the fact that at least three distinct species of cattle ticks had to be dealt with and that some of the indigenous wild animals are bovines.

III. TICK INFESTATION.

Apart from causing tick fever, a few infesting ticks do not give rise to any appreciable inconvenience, but when they exist on a beast in numbers, they cause constitutional disturbances.

The first indication of heavy tick infestation is irritation. Evidence of local inflammation soon becomes manifest about the points of attachment, which are usually on the parts where the skin is thin. As the ticks increase in number, the irritation produced becomes so great that the infested beast is in an almost continuous state of unrest. In gross infestation, parts such as the escutcheon, scrotum, and flanks, where the ticks attach themselves in countless numbers, become inflamed, corrugated and fissured, gangrene supervenes, and often patches of skin the size of one's hand slough off, leaving nasty ulcerated sores which quickly become fly-blown if left unattended. Pendent parts, such as the dewlap and scrotum, become dropsical, and superficial lymph glands stand out prominently. The affected animals grow dull and listless, not caring to move in search of food, stand in shade not far from water, lose condition daily, and soon present a miserable appearance.

The condition produced by gross infestation is variously known as tick worry, tick poverty, and tick anaemia. It was first clearly described in Queensland by the late Dr. Sydney Hunt, in connexion with the Boolburra cattle, which showed symptoms of fever, anaemia and exhaustion, and many of which died. Hunt showed that the degree of anaemia was roughly proportional to the number of infesting ticks and the condition was quite distinct from that due to tick fever, although, as has been previously pointed out, tick fever and tick worry may concurrently affect the same beast. Cattle suffer more severely from tick worry when in low condition, particularly if the fodder is dry and scarce, as in periods of drought. Moreover, cattle newly exposed to infestation not only suffer to a greater degree from tick irritation than those accustomed to ticky pastures, but they become more grossly parasitized. Those born and reared on infested pastures seem to a certain degree to become habituated to the tick.

Horses at pasture also suffer from tick irritation very keenly. They rub themselves violently, nibble and bite affected parts until bleeding abrasions are produced, become listless, lose condition, and cannot stand work. Horses groomed and worked seldom become grossly infested.

IV. TICK FEVER.

(1) General.

The best known synonyms of this disease are Texas fever, bloody murrain, southern cattle fever (United States of America), bovine malaria (Europe), tristeza (South America), red water (South Africa, Great Britain, and Australia), bovine piroplasmosis and babesiosis bovum. By the name red water, it was extensively known in the Northern Territory and Queensland, owing to red-coloured urine being voided by some of the affected animals; but as haemoglobinuria (red water) is a symptom common to several affections, the use of this synonym is to be discouraged.

Tick fever is a specific disease of cattle caused by a protozoan parasite, the *Piroplasma bigeminum* or *Babesia bigemina.* In natural conditions there is no reason to suppose that the disease is spread by means other than the cattle tick. It can, however, be reproduced in susceptible animals by artificial inoculation with fresh blood of an affected beast; but exposure to urine, manure and nasal secretions of sick animals, and to blood and viscera of cattle dead of the disease, has always been attended with negative results. An affected animal may, upon recovering, regain good health, become well-conditioned, and cohabit with susceptible animals without harm accruing; but as soon as the cattle tick is introduced and develops upon it, the recovered beast becomes a serious source of danger to uninfected cattle.

When the disease is induced by artificial inoculation, the period of incubation usually ranges from three to ten days. When naturally acquired by exposing susceptible animals to tick-infested pastures, the first manifestation of the disease is usually seen between the tenth and eighteenth day, and the influence of certain factors, such as age, sex, condition, season and nourishment, upon the symptoms of tick fever has long been recognized. Young cattle, and particularly sucking calves, are more resistant to acute tick fever. Bulls (yearlings and over) are prone to suffer the fever in its most acute form, the fatality in adult bulls being from 80 to 90 per cent. Adult unprotected cattle usually manifest a severe type, and 40 to 60 per cent. may die, those carrying extremes of condition generally suffering most. The disease exists in its most acute form during summer and autumn months, and mortality is always accentuated when the season is dry and fodder scarce. The management of the animals during their illness also has a marked influence on the severity of the attack. Extremes of climatic temperature, excitement and exhaustion caused by worrying, droving and search for food greatly reduce the chances of recovery. On the other hand, losses are greatly minimized when the cattle are stalled and nursed, or are left undisturbed in paddocks containing succulent fodder, good shelter, and an ample supply of water easily accessible.

(2) Clinical Manifestations.

The chief clinical manifestations of an acute attack of the disease are fever, hurried respiration, increased pulse, suppression of milk yield, icterus, gastro-intestinal derangement, anaemia, emaciation, and haemoglobinuria. As a rule, the onset of fever is sudden and the initial stage is usually intermittent in character, there being a sharp fluctuation between morning remissions and evening exacerbations; but as the thermal crisis approaches, the temperature tends to become constantly high and the variations less marked, after which it generally falls to normal or sub-normal. The duration of the fever is from four to ten days, the average being seven days. The visible mucous membrane of the eye is at first red and injected, but quickly becomes anaemic and often of a yellowish hue. In milch cows the secretion of milk becomes suppressed, and what little can be drawn has a thick creamy appearance. While total suppression may occur, as a rule the cessation of lactation is but temporary, and more or less complete restoration is dependent upon the care and management of the cow whilst ill. If well nursed and judiciously fed, and the udder milked dry at the usual periods during sickness, the cow not infrequently comes back to almost her full milking capacity.

During the progress of the fever the blood becomes thin and watery, owing to the destruction of the red corpuscles by the piroplasmata, and the affected animals rapidly become emaciated, weak, and anaemic. The extent to which the number of corpuscles becomes diminished is in proportion to the acuteness and severity of the attack. In acute natural fever, the loss of red corpuscles as a rule amounts to between 25 and 75 per cent., but in isolated cases it may be still greater. A case is recorded where the number of red blood corpuscles fell at the onset of fever from 8,200,000 to 1,800,000 per c.mm., while on the next day, a few hours before death, only 31,000 per c.mm. were counted. The anaemia reaches its full extent on about the seventeenth day, and as recovery ensues the number of red blood cells becomes normal again at various times between the twenty-third and ninetieth day.

Haemoglobinuria, or "red water," as it is popularly called, often becomes manifest to the naked eye in acute cases, but this symptom is not a constant one, as many animals suffer from acute fever and some may die without its ocular evidence. Death usually occurs within one to seven days, and may take place when the fever is at its height, or, as is more common, subsequent to a marked fall of the body temperature to normal or sub-normal within a few hours. In non-fatal cases, the temperature gradually falls after the crisis, and reaches normal in a few days, while the natural functions of organs are slowly restored. Poorly-nourished animals may show subcutaneous oedema in pendulous parts for some time. Occasionally complications arise, especially abortion.

In addition to acute fever, a mild type and a chronic type are recognized. In the mild type the fever does not exceed 105° F., and the natural functions and general conditions are but temporarily interfered with, and to a slight extent. In practice it is usual to regard as belonging to this type all gradations from acute fever to an attack so mild as to pass almost unobserved clinically, if the microscope and thermometer are not brought into requisition. Convalescence is usually of short duration, and the loss of flesh may be slight in well-nursed animals, but under adverse conditions it may be considerable. This type is most frequently seen as the result of artificial inoculation, and rarely causes mortality exceeding 5 per cent. It, however, is apt to increase the severity of co-existent diseases.

The chronic type of the disease is not common. Occasionally an animal will survive an acute or mild attack, and instead of recovering its normal healthy appearance within the usual period, it remains for a long time in a condition resembling pernicious anaemia. It acquires an emaciated, unthrifty appearance, becomes stunted in growth, the coat grows shaggy and rough, the appetite is capricious, the rumination sluggish, the heart is irritable and visible mucous membranes are pallid.

Occasionally animals that recover from the acute and mild types suffer relapses, which are often mild and fleeting, but at other times severe and even fatal. These relapses may occur without the presence of the tick.

(3) Post-mortem Lesions.

The post-mortem lesions of an animal which died of tick fever are usually well-marked and fairly characteristic. The more pronounced pathological changes are found in connexion with the blood, serous membranes, liver (including gall bladder), spleen and kidneys, and have been fully recorded by many observers. Consequently the differential diagnosis of tick fever is not a perplexing matter to the trained veterinarian, and confirmation by microscopic examination of blood from recent cases is usually definite.

(4) Treatment.

As previously indicated, young cattle left undisturbed in sheltered localities, with sufficient green fodder and a plentiful supply of water readily accessible, seldom suffer the fever in its most virulent form. Even with grown cattle, other than bulls and pregnant cows, mortality may not be heavy under these conditions without medicinal treatment of any kind. Still, in many instances, owing to either adverse conditions or natural susceptibility of the animal, or possibly prevalence of fever of exalted virulence, the mortality has been so heavy that medicinal treatment has been indicated, and the usual therapeutic agents have been used, but without much success.

In 1909, as the result of their work in connexion with canine piroplasmosis, Nuttall and Hadwen recommended the use of trypan blue, to be administered subcutaneously or intravenously in doses of from 100 to 200 c.c. of a 1 per cent. solution. This treatment has been favorably reported upon by several observers, particularly in South Africa, as it is stated that the injection of the drug in the majority of cases is followed by an immediate increase in fever for 24 to 48 hours, and a subsequent fall of temperature to normal, accompanied by speedy recovery. With the fall of temperature, marked destruction of the parasite occurs; but the destruction is not complete, as a small proportion survive. It is claimed that the drug is most effective when injected at an early stage of the disease, and while good results may be anticipated if administered when the fever is at its height, its efficacy in advanced cases is not to be relied upon with confidence. The drug when properly administered appears to produce no ill effects upon the health of the animal, but being a dye, has the disadvantage of colouring the tissues for some considerable time. Experiments by Dodd in Queensland in 1909 and 1910 were reported by him as indicating that trypan blue, in cases of tick fever, was in the main an effective remedy when used at an early stage of the disease, but work by Cory and Pound has failed to substantiate these results.

(5) Protection.

It has long been recognized that an animal recovered from an attack of tick fever possesses a degree of protection against a second attack, and advantage has been taken of this fact to prepare animals for exposure to virulent pathogenic ticks. This is carried out by inducing fever artificially by inoculation.

Protective inoculation consists in the subcutaneous or intravenous injection of susceptible animals with the blood of a beast containing the causal piroplasma. The dose usually injected varies from 3 c.cm. to 5 c.cm. (about half to one teaspoonful), although the fever has been caused by much smaller quantities. Experimental doses of over 100 c.cm. have been given without death occurring. The inoculation is followed by a period of incubation, usually of three to eleven days, the average being about seven, though in some cases even 20 days may elapse. The injection of blood intravenously may be followed by a shorter incubation period than when used subcutaneously. As a rule, a short period of incubation is followed by an acute attack, and a lengthened period by an unsatisfactory reaction. The resulting sickness and temperature reaction are by no means constant in severity, and would appear to be dependent largely upon the infectivity or quality of the blood used to reproduce the fever, and the natural susceptibility of the inoculated animal.

The infectivity of the blood varies both in degree and duration in individual beasts. It may show recurrences and exacerbations, and the quality of infectivity is not identical with tolerance to the fever. Consequently the fact that a protected animal remains unaffected on subsequent exposure to the disease, whether acquired naturally or by inoculation, is of no service as an indication of the value of its blood for inoculation purposes. It is obvious that to ensure good results the quality of the blood used should be reliable.

Tick fever induced by inoculation is similar to the disease naturally acquired, but as a rule is of a modified nature. It is very liable to be affected by the same conditions that influence naturally-acquired fever. Adult bulls and pregnant cows always suffer severely, while the mortality in adult bush cattle and young bulls is, as a rule, from 2 to 5 per cent., but may be considerably higher. In bush cattle under one year old, and in quiet stall-fed stud or dairy cattle, under favorable conditions, death rarely ensues, and similarly the appearance of a relapse subsequent to the reactional fever following inoculation is rare. The duration of the fever is usually shorter than when acquired naturally; occasionally it may last eleven days, but very rarely becomes chronic or even prolonged. Not only does inoculation afford a decided protection against tick fever, but this protection is rapidly produced, being manifested as early as the sixth day after subsidence of the fever. The protection is not absolute, and is more of the nature of a tolerance than of an immunity. Its duration and degree are subject to variation, and would appear to depend largely upon the idiosyncrasy of the animal.

Under natural conditions cattle running on pastures containing infective ticks are continually subjected to successive inoculations by these parasites, and protection is in this manner maintained throughout life. With cattle depastured in clean country, that have been protected by artificial inoculation, one may safely assume that the majority enjoy a protection for a period of from one to two years, and occasionally with individual beasts it may last longer.

The indication of the value of the inoculation of each beast is to be sought in the reactional quality of the blood used, and this is best obtained by microscopic examination of the blood of the treated animal. Where this is not practicable, the morning and evening temperatures should be recorded systematically to ascertain the nature and degree of the febrile disturbance that follows, but it must be remembered that some animals although infected show no rise in temperature. When a large number of cattle are inoculated, this should be done with one or two quiet beasts that were inoculated at the same time with some of the blood used for general inoculation of the herd.

When the tick spread down the Queensland coast, it was a practice to inoculate herds in its advance in order to obviate the serious mortality that occurred in the northern herds. An inoculated beast, however, acts as a reservoir of infection, as the infesting ticks extract from it the piroplasma and thus spread the disease. As already pointed out, all cattle ticks are not infective, and there is little doubt that protective inoculation was an important factor in the dissemination of tick fever in certain centres in Queensland.

In Queensland, protective inoculation is still extensively carried out. Yeerongpilly Stock Experiment Station, and its branch at Townsville, supply infective blood, and prepare a large number of "bleeders" for station use. As the cattle tick in New South Wales is not infective, inoculation is prohibited in that State.

V. METHODS ADOPTED FOR ERADICATION.

(1) General.

From the foregoing it is evident that the eradication of the tick is of primary importance, for without the tick there can be no tick fever. From the summary of the life-history given, it is evident the tick must be attacked either during its parasitic development on its host or during its existence on the pastures.

It is considered that the most efficacious method of controlling the pest is to attack the tick during its parasitic existence.

The methods employed are—

(*a*) *Hand-dressing and Spraying.*—Small lots of quiet cattle and horses are sometimes treated by this process, particularly at remote parts of the quarantine boundaries where the traffic is light, and on isolated farms some distance removed from a dip. It is also used in the treatment of animals in advanced pregnancy and injured animals, but speaking generally, its efficacy depends on the thoroughness with which it is performed and the completeness of saturation of the animal's coat with an effective solution. The process, however, is laborious and relatively expensive.

(*b*) *Dipping.*—The most expeditious and efficacious method of treating infested animals is undoubtedly dipping. It is the only practical method of treating unhandled cattle and horses. For the treatment of large numbers it is also the cheapest method. In dipping, the animals are caused to plunge into a tick-destroying solution contained in a narrow tank, so as to become completely submerged, and on rising to the surface to swim for a short distance.

Another method of destroying ticks is the freeing of pastures by the "starving-out method," which consists in excluding all possible hosts of the tick from the pastures until sufficient time has elapsed for the tick to die out and the eggs to perish. In practice, it is usually combined with the "feed-lot" or "pasture rotation" system, which consists in moving infested stock from paddock to paddock in rotation at definite periods, so that the cattle are removed systematically to clean pastures before the eggs laid by the matured females that drop from them have time to hatch out. Upon removal of the cattle, the land recently vacated is placed under cultivation, and it is not re-stocked until sufficient time has elapsed to assure death of the progeny of the ticks that were dropped there. There exist no reliable data as to the safe limit of this period in Australia, although field observations in the north coast districts of New South Wales indicate that it exceeds one year. In America, where this system has been practised, it is usual to remove the cattle every twenty days during the season when the tick thrives, and the result is reported as satisfactory in certain localities. The success of the system is necessarily dependent upon a more efficient control of stock than exists in this country, and at best is applicable only to specially-selected localities. In all cases there is the danger of re-infestation of the pastures by agencies difficult to control, and as a practical method for general adoption in Australia it does not commend itself, although it may be applicable in isolated cases. With this system, as with all other methods, improvement of the pastures, burning-off, and cultivation are valuable adjuncts.

(2) Dipping.

Many substances fatal to ordinary parasitic insects have but little or no effect upon the cattle tick, owing to its extreme tenacity of life. Others poisonous to the ticks are equally fatal to the host. Numerous experiments have been carried out in America, Australia, and South Africa, with a view to the discovery of an agent capable of general application that will destroy the tick without incurring any risk of injury to the host when dipped in it.

Experience indicates that arsenic is the most reliable tick-destroying agent at our disposal. Certain official formulae are adopted in New South Wales and Queensland, and in the latter State are incorporated in regulations promulgated under a State enactment. In addition, there are a number of proprietary mixtures on the market which receive official recognition. The official formulae are as follows :—

Formula used in Queensland (A)—

Arsenious oxide	8 lb.
Caustic soda	5 lb.
Stockholm tar	½ gallon
Tallow or oil (animal or vegetable) ..	4 lb.
Water	400 gallons

Directions.—Mix from 8 to 8½ lb. commercial arsenic (to contain 8 lb. arsenious oxide) in its powdered dry state intimately with 2 lb. of caustic soda, and, while stirring, add slowly up to 4 gallons of water. Heat to boiling point if arsenic has not properly dissolved. Then boil from 50 to 100 gallons of water in a 400 gallon tank, add 2 lb. of caustic soda and 4 lb. of tallow (or oil); boil for about 15 minutes, then add slowly in a thin stream half a gallon of the best Stockholm tar. When the whole of the tar has been added, boil from 30 to 40 minutes, then add the arsenical solution and fill up the tank with water.

Formula used in Queensland (B)—

Arsenious oxide	8 lb.
Caustic soda	4 lb.
Bone oil	1 gallon
Water	400 gallons

Directions.—Mix from 8 to 8½ lb. of commercial arsenic (to contain 8 lb. of arsenious oxide) in its powdered dry state intimately with 2 lb. of caustic soda. In a separate vessel add 2 lb. of caustic soda to 1 gallon of bone oil, heat for about fifteen minutes with constant stirring, withdraw for five minutes, and then while stirring add cautiously the dry arsenical mixture. Now add hot water to make on stirring a thin homogeneous paste, then add cold water up to 400 gallons.

Formula used in New South Wales.

The composition of the medicament used for tick eradication purposes in the quarantined area of New South Wales is as follows:—

Arsenious oxide	6 lb.
Caustic soda	1½ lb.
Potash soap	3 lb.
Stockholm tar..	3 pints
Water	400 gallons

Stock leaving the quarantined area for clean country are treated in the following (stronger) solution:—

Arsenious oxide	8 lb.
Caustic soda	2 lb.
Potash soap	4 lb.
Stockholm tar..	4 pints
Water	400 gallons

The medicament is manufactured in concentrated form in the laboratory at Lismore, whence it is issued in two sets of containers to the various baths to be mixed with water in definite proportions as required.

The composition of the "concentrate" is 4 lb. arsenious oxide per gallon, in the form of sodium arsenite, that of the "emulsion" being 4 lb. potash soft soap together with half a gallon of neutralized Stockholm tar per gallon.

These are added separately to the mixing tanks, and dissolve readily in cold water.

Application of the Medicament.—For treatment to be effective, it is necessary that the medicament containing the standard percentage of active arsenic be applied to the whole of the external surface of the animal's body. To maintain the standard desired, periodical chemical examination of the medicament, especially when contained in dipping vats for long periods, is very important, and should be efficiently carried out. This procedure is carried out in New South Wales every 21 days, and is recommended.

The effect of these arsenical preparations is not immediately noticeable, and one treatment cannot be relied upon to clean a beast of the parasites. For eradication of the pest, the treatment must be continuous and systematically carried out.

The fact that the cattle tick takes about 21 days to develop upon the host permits of opportunity for its destruction before it matures.

In the experience of the United States of America (Farmers Bulletin No. 1057, U.S.A. Department of Agriculture), it would appear that fourteen (14) days is the most satisfactory interval to be adopted between treatments.

(3) Investigations of the Cattle Tick Dip Committee in Queensland.

Initiation of Investigations.—A proposal was made in 1918 by the late Institute of Science and Industry for the establishment of a Special Committee to superintend investigations into cattle tick dips in relation to tick control and eradication. It was ultimately decided in December, 1919, that the proposed Committee should be formed and have its head-quarters in Brisbane.

The present personnel of the Committee is as follows :—

G. E. Bunning (Chairman) W. A. N. Robertson, D.V.Sc., Director of Veterinary Hygiene, Commonwealth Department of Health E. J. Goddard, B.A., D.Sc., Professor of Biology, University of Queensland	Representing the Commonwealth Council for Scientific and Industrial Research
J. C. Brunnich, Agricultural Chemist, Queensland A. H. Cory, M.R.C.V.S., Chief Inspector of Stock, Queensland C. J. Pound, Government Bacteriologist and Director of the Yeerongpilly Experiment Station, Queensland H. Tryon, Government Entomologist	Representing Queensland
Max Henry, M.R.C.V.S., Chief Veterinary Surgeon, New South Wales A. A. Ramsay, Chief Agricultural Chemist, New South Wales C. J. Sanderson, M.R.C.V.S., Senior Government Veterinary Surgeon, New South Wales C. L. O'Gorman, M.R.C.V.S., Chairman of the Board of Tick Control, New South Wales L. Cohen, Chemist, Board of Tick Control, New South Wales	Representing New South Wales

Nature and Scope of Investigations.

At the initial meeting of the Committee held in Brisbane on the 24th and 25th March, 1920, it was decided to conduct investigations in conformity with those suggested at the Conference of Delegates appointed by the Institute of Science and Industry, as set out in Item 7, page 36, of Bulletin No. 13, and which reads as follows :—

> Although the present official formulae used in Queensland and New South Wales have proved to be efficient and generally satisfactory, it is possible that the same parasiticidal results might be maintained and the ill effects that sometimes occur obviated by alteration of the composition of the agent.
>
> There is evidence that solutions containing a lower arsenical content than officially stipulated are effective in the hotter parts of Queensland. It is possible that it will be found that the strength of the parasiticide used may with safety be varied according to the time of the year, and the climate of the locality where it is used. With a view to determining the limitations, experimental investigation is deemed necessary.

The Committee, during the course of the experiments, found that it would be desirable in some instances to enlarge and in others to modify the scope of the investigations to cover any collateral questions which might arise in the course of the conduct of the work, and permission was obtained from the Institute to do so.

Scheme of Investigations and Progress of Work.—Field Experiments.— It was decided to conduct field operations to ascertain the optimum arsenical strength, i.e., the minimum effective amount of arsenious oxide required in a medicament, either alone or combined with Stockholm tar and soap (emulsion). These investigations were conducted at Tallebudgera (Queensland) from 19th January, 1921, to the 20th April, 1921, and at Oxenford (Queensland) from 2nd June, 1921, to the 12th June, 1921. The experiments were definite in one point only—that no concentration of medicament used killed all the ticks as a result of one application. A decision was subsequently arrived at to make use of the Stock Experiment Station, Yeerongpilly, Queensland, for the purpose of carrying out further investigational work.

Experiments at Stock Experiment Station, Yeerongpilly, Queensland.

Experiment No. 1.—Action of standard arsenical dip fluid on ticks during the moulting stage.

This experiment was carried out in March, 1923.

Experiment No. 2.—The extent, if any, of the protective action of medicament against re-infestation by larval ticks.

This experiment was first carried out in March, 1923, and repeated in June, 1923.

Experiment No. 3.—The effect of subsequent rainfall on the efficacy of treatment.

This experiment was carried out in June, 1923.

Conclusions based on initial experiments.—The investigations definitely established the following facts :—

1. No single treatment with fluids of concentration up to 10 lb. of arsenious oxide per 400 gallons and containing up to five times the prescribed standard proportion of saponified tar, is efficacious in destroying ticks in all stages of development on an infested animal.
2. The survivors from such treatment are adults, and in a stage of development not inconsistent with the hypothesis that they were undergoing the second moult at the time of treatment.
3. Some survivors lay a full complement of eggs which duly hatch.
4. A single treatment with arsenical solutions up to full standard strength shows no superiority in destroying all the ticks, over those of half-strength and upwards.

The following tentative conclusions were also arrived at, the correctness of which was subject to modification in the light of more elaborate projected experiments :—

(*a*) Treatment with the prescribed standard arsenical fluid affords protection against re-infestation by larval ticks for a period of two days.

(*b*) Heavy rain falling on cattle four hours subsequent to treatment does not diminish the efficacy of such treatment, provided the cattle had dried in the interim.

(*c*) During the second moulting period of the ticks' parasitic life, a phase exists in which the tick is resistant to the action of arsenical fluids, and the existence of surviving adult females after treatment is apparently due to such a phenomenon.

As Experiment No. 3 demonstrated that the tick destroying properties of the arsenical solution were not materially impaired when sprayed cattle were subjected to the effect of hosing with water (simulating rain) at a minimum interval of four hours, it was decided to repeat the experiment in order to determine how soon after dipping a shower of rain would influence those properties.

Experiment No. 3 (*supplementary*).—To test further the effect of rain on tick infested cattle that had been recently treated with standard arsenical dip solution.

The results of this investigation, which was carried out in September and October, 1923, indicated that the tick destroying properties of the standard arsenical solution are considerably reduced if sprayed animals are subjected to rainfall at a short interval after treatment, as was shown in the animals which were hosed half an hour, one hour, and two hours after the application of the dipping fluid.

Experiment No. 4.—To test the comparative effect of two applications of dipping fluid at short intervals, and at strengths of 4, 5, and 8 lb. of arsenious oxide, per 400 gallons of water.

This test, which was carried out in November, 1923, did not give conclusive results.

Experiment No. 5.—To determine the minimum amount of arsenic (combined with soap and tar) necessary to kill all ticks with two sprayings.

This test was carried out in October, 1924, and it was agreed that the result determined that the minimum amount of arsenic (combined with soap and tar) necessary to kill all ticks with two sprayings, was 8 lb. to 400 gallons of water.

Experiment No. 6.—To investigate the effect of the omission of emulsion from the official formula.

As a result of this experiment, the opinion was formed that the omission of Stockholm tar and soap from a dipping fluid clearly showed that the efficacy of that fluid was diminished as a tick destroying agent. Furthermore, it was indicated that the addition of Stockholm tar and soap had a protective effect on the skin of the animals submitted to treatment with arsenical fluid.

Experiment No. 7.—To ascertain whether (the percentage of arsenious oxide remaining constant) the efficacy of the dipping fluid is diminished by continuous use.

After consideration it was decided that experiments in this connexion were not necessary.

Experiments No. 8 *and* 9.—

No. 8. To find a substitute for Stockholm tar, which varies considerably in composition and is difficult to obtain.

No. 9. To ascertain whether a decreased amount of arsenic can be compensated for by an increased amount of Stockholm tar or substitute therefor. (It is considered that to a certain extent any injurious effect of the dip must be in proportion to the quantity of arsenic, whereas soap and emulsions have an emollient effect.)

These experiments were carried out in conjunction. As only one tick survived which hatched viable eggs, it was obviously impossible to make any comparison between the tar and the resin which was used as a substitute. It was therefore decided to repeat the experiments with modifications.

Experiments No. 8 *and* 9 (*repeated with modifications*).—

The results of these experiments indicated—

(*a*) That resin can be used as an efficient substitute for tar.

(*b*) That double the amount of tar does not compensate for the omission of quarter the amount of arsenic.

Experiment No. 10.—*Commercial Concentrates.*—Although many concentrates give good results when freshly prepared, it is a well known fact that the liability to oxidation varies. Concentrates which show exceptional liability to oxidation cannot be recommended for general use in substitution for the official formula. It was therefore decided that before the experiments were conducted on cattle, the comparative oxidation be first determined on a laboratory scale. For this purpose, it was arranged that small quantities—approximately 4 gallons—of the various standard strength commercial concentrates, approved under Government regulations, be exposed to the air after the addition of a small amount of bovine excreta, and the rate of oxidation determined by periodical analyses.

The experiment indicated that before the addition of milk (i.e., during a period of about two months), all concentrates oxidized to a greater or lesser extent. In one case, after the addition of milk there was an immediate reversion which was maintained for a further two months. This was probably due to the absence of antiseptic substances in that particular concentrate. As this experiment was carried out on the small scale originally suggested, it must not be understood to indicate that a parallel rate and extent of oxidation takes place in a dipping bath, owing principally to the difference in ratio of surface to volume of fluid as well as to local conditions, such as soil, &c., the process being of biological origin.

As the results of this experiment carried out on a laboratory scale indicated liability to oxidation, it was decided that there was no necessity for further experiments on a field scale.

Experiment No. 11.—*Prevention of Oxidation of Dipping Fluid.*—As experiments by the New South Wales Department of Agriculture had shown that, in the absence of much germicidal material, the addition of 2 per cent. of skim milk to the dipping fluid both prevents oxidation and brings about the reduction of any arsenate already formed, steps were taken to confirm this in dips charged with dipping fluid which had been oxidized to a considerable extent.

The result of this experiment clearly indicated that the addition of 2 gallons of skim milk per 100 gallons of dipping fluid brought about complete reduction of the arsenate into arsenite under field conditions. These tests were carried out by officers of the Department of Agriculture and Stock, Queensland. In several other tests carried out at the instigation of the Committee by stock owners in various parts of Queensland, similar results were revealed. The adoption of this practice for general use can therefore be confidently recommended.

Experiment No. 12.—Test of Derris root (Tuba root) or its manufactured products, as a tick destroying agent.

It was arranged to dilute an extract from the powdered root of *Derris elliptica*, add the usual quantity of potash soap, spray three head of moderately infested animals, and compare the results with a similar number of untreated controls.

The result established the fact that although the derrisine solution kills a considerable proportion of the ticks, it has no practical value as a tick destroying agent.

(4) Summary of Investigations of the Tick Dip Committee.

A summary epitomizing the findings of the Committee, based on the investigations carried out, was adopted as follows :—

1. The field experiments showed that at Tallebudgera, where the experimental cattle had to be driven some 2 miles to the dip, and the weather was hot and humid, epidermal exfoliation (scalding) took place even at the lowest arsenical strength employed, whereas at Oxenford, where the weather during the experiment was cold and the cattle were depastured on the holding on which the dipping took place, no scalding was noted.

This would support the view that dipping in arsenical solutions, *per se*, used in the concentrations commonly employed, does not cause injury to the skin unless other factors such as humidity or driving prior or subsequent to dipping are present.

2. No single treatment with fluids of concentrations of from 4 lb. to 10 lb. arsenious oxide per 400 gallons, or containing up to five times the prescribed standard proportion of saponified tar, is efficacious in destroying all ticks in all stages of development on an infested animal; and further, during the second moulting period of a tick's parasitic life, a phase exists in which the tick is resistant to the action of arsenical fluids. The existence of surviving adult females after treatment is apparently due to such a phenomenon.

Some survivors lay a full complement of eggs which duly hatch.

3. Treatment with prescribed standard arsenical fluid as set out in paragraph 5 affords protection against re-infestation by larval ticks for a period of two days.

4. Heavy rain falling on cattle subsequent to treatment does not diminish the efficacy of such treatment provided that not less than two hours had elapsed and that the cattle had been dry in the interim.

5. While two treatments, at an interval of two or three days, with medicament containing 8 lb. of arsenious oxide, ½ gallon of Stockholm tar and 5 lb. of potash soap to 400 gallons, do not actually kill all the ticks present on an animal at the time of the initial treatment, these repeated applications are successful in preventing the propagation of such ticks by destroying the fertility of the resultant eggs.

6. The result of the experiments indicates that the minimum proportion of arsenious oxide (in conjunction with Stockholm tar and potash soap) necessary to prevent the propagation of all ticks by two sprayings of the animals at an interval of three days is 8 lb. per 400 gallons.

7. The omission of Stockholm tar and soap from the dipping fluid diminishes the efficacy of that fluid as a tick destroying agent, but soap is not weight for weight an efficient substitute for Stockholm tar.

Resin can be used as an efficient substitute for Stockholm tar, and 4 lb. of resin were found to be more effective than half a gallon of tar.

8. Oxidation in dipping baths can be prevented or rectified by the addition of 2 per cent. skim milk or butter milk, or an equivalent amount of casein or dried butter milk.

(5) Present and Projected Activities of the Tick Dip Committee.

The desirability of adopting uniform efficacious methods for the cleansing of cattle for eradication purposes has already been emphasized. To secure this uniformity in dipping methods in the States concerned, it is essential that information based on conclusive investigations should be secured so that the dipping regulations imposed shall be such that a maximum of results is secured at a minimum risk to the cattle treated. To obtain the objective indicated, it is essential that experiments under natural conditions should be carried out in a suitable location where the isolation of the experimental cattle can be provided for in order to determine—

(*a*) the most suitable interval between dippings, and
(*b*) the optimum composition of the dipping fluid,

by observing the time required to eradicate all ticks on the experimental holding.

It has been agreed that the following solutions and intervals should be adopted :—

(*a*) 8 lb. arsenious oxide at 14 days' interval.
(*b*) 6½ lb. arsenious oxide at 18 days' interval.

Suitable experimental paddocks have been secured at Samford, near Brisbane, experimental cattle have been purchased, and all arrangements have been made for this investigational work, which is now about to be initiated.*

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* These experiments have now (April 1929) been in progress for some time.

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PAMPHLET No. 13

COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

THE

MECHANICAL ANALYSIS OF SOILS

By

C. S. PIPER, M.Sc., and H. G. POOLE, M.Sc.,
Waite Agricultural Research Institute

MELBOURNE, 1929

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CONTENTS.

The Mechanical Analysis of Soils.*

By C. S. Piper, M.Sc., and H. G. Poole, M.Sc.,† Waite Agricultural Research Institute.

1. General.

While Pamphlet No. 8 of the Council for Scientific and Industrial Research (6) was in the press, the method for the mechanical analysis of soils, as officially adopted by the Agricultural Education Association of Great Britain, was modified to conform to a newly-adopted International method. Corresponding changes have now been made in the method in use at the Waite Institute, and the purpose of this paper is to supplement Section III. (pp. 10–20) of the aforementioned pamphlet (6). The use of an end runner grinding mill for the preparation of soil samples, and a motor dispersion unit, are also discussed.

It is to be hoped that the International method will be extensively adopted throughout Australia, so that the results of mechanical analyses of soils will be comparable with those obtained in other parts of the world.

2. The International Method for the Mechanical Analysis of Soils.

(*a*) *Development of an International Method.*—

One of the functions of the International Society of Soil Science is the standardization of methods for the examination of soils, so that results obtained in any one country will be directly comparable with those obtained elsewhere. The first of such methods to receive international acceptance is the method for mechanical analysis. A preliminary meeting of Commission I. of the International Society (Soil Physics) was held at Rothamsted in October, 1926, and, as a result of the deliberations of representatives of different countries, tentative proposals were formulated for an International method. With only minor modifications, this method was adopted at the Washington Conference of the Society in June, 1927. In a number of countries, it will mean the introduction of some changes in the methods and standards in use at the present time, but the benefits to be derived will far outweigh any inconvenience due to the change.

In 1928, the International method was adopted by the Agricultural Education Association of Great Britain (1, 2), thus superseding the method adopted two years previously. Results obtained by the older method can be transposed to the new system by interpolation from summation curves and a knowledge of the loss on ignition of each soil fraction. (See Section *e*.)

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* Manuscript received 6th May, 1929.

† Of these two authors Mr. Piper is an officer of the University of Adelaide, and Mr. Poole an officer of the Council for Scientific and Industrial Research.

(b) *The major differences between the International and the former British Methods.*

The chief differences between the two methods are the separation of four groups of particles instead of five, and the recording of these fractions on the oven dry instead of the ignited basis.

In the International method the results are expressed as percentages of the oven dry sample. It is our experience that an oven dry soil should never be used in the analysis, as in some cases it has been found to lead to difficulties in the dispersion when using the pipette technique. Keen (5) considers that in the past the air dry moisture content of a soil has been found to be a very useful determination, enabling some idea to be formed of the probable effect of the clay and organic matter on the moisture relationships of the soil in the field. For these reasons, and because the values expressed as percentages of the air dry sample can be easily converted to the corresponding oven dry figure by a simple calculation, it is proposed to retain this method of expressing the results. This is in accord with the present British practice.

The limiting dimensions and the critical settling velocities of the fractions in the International and old British methods are given in Table I.

The settling velocities used in the International method are derived from Stokes' law on the assumption that particles with a settling velocity of 10 cm. in 8 hours at 20° C. have a diameter of 0·002 mm. Corrections due to the change of the viscosity of water with temperature have to be applied to the above settling velocities. (See Table II.)

In the International method a 70 mesh I.M.M. sieve is used for the separation of the fine and coarse sand fractions instead of the 90 mesh sieve used in the old British method. When the latter sieve is used the upper limit of the fine sand is only 0·14–0·155 mm. in diameter (not 0·2 mm. as given). This accounts for its assumed settling velocity (shown in the last column of Table I.) being lower than that of the corresponding International fraction, which actually has a limiting diameter of 0·2 mm.

The recording of the results of all the fractions on the oven dry instead of ignited basis constitutes the biggest difference between the two methods. The old British method was about the only method in which the fractions were ignited, the object being to remove organic matter, but the introduction of the hydrogen peroxide pre-treatment has largely removed the necessity for this ignition. All the fractions will be greater if reported on the oven dry basis, but the difference will fall mostly in the clay, the water of constitution, which was formerly removed by the ignition, being retained. For some time it will therefore be desirable to determine the clay on both the oven dry and ignited basis.

The loss on ignition, although not included in the International method, should still be determined and recorded separately. Together with the ignited value of the clay fraction it gives a useful check in routine analyses, since the summation of the results, including the loss on ignition and using the ignited value instead of the oven dry for the clay, should approximate to 100 per cent.

Table I.

Comparison of International and Old British Systems of Classification.

International System.			Old British System.			
Description of Particle.	Diameter of Particles.	Maximum Settling Velocity.	Description of Particle.	Diameter of Particles.	Maximum Settling Velocity.	
	mm.	At 20° C.		mm.	At 15° C.	At 20° C.
			[Fine Gravel] ..	2·0–1·0 ..	305 cm. sec.	347 cm. sec.†
Coarse Sand ..	2·0–0·2 ..	347 cm. sec...† ..	Coarse Sand ..	1·0–0·2 ..	76 cm. sec.	87 cm. sec.†
Fine Sand ..	0·2–0·02 ..	3·47 cm. sec.† ..	Fine Sand ..	0·2–0·04 ..	1·85 cm. sec.	2·1 cm. sec.†
Silt	0·02–0·002 ..	10 cm. in 4 min. 48 sec. = ·0347 cm. sec.	Silt	0·04–0·01 ..	30 cm. in 5 min. = ·1 cm. sec.	·114 cm. sec.
Clay	Below 0·002	10 cm. in 8 hours. = ·000347 cm. sec.	Fine Silt ..	0·01 0·002 ..	12 cm. in 20 mins. = ·01 cm. sec.	·0114 cm. sec.
			Clay	Below 0·002*..	8·6 cm. in 24 hours = ·0001 cm. sec.	·000114 cm. sec.

* The calculated upper diameter of British Clay is actually 0·0014 mm.

† Assumed for purposes of interpolation.

(c) *Analytical Details.*—

No alteration is required in the moisture, loss on ignition, and loss on acid treatment determinations, and the hydrogen peroxide treatment*, acid treatment, filtration and dispersion of the 25 grm. sample are exactly as described in the pamphlet (pp. 12–16), except that a 70 mesh I.M.M. sieve is used instead of a 90 mesh sieve in the dispersion.

Pipetting the samples.—After 16–18 hours shaking the soil suspension is diluted in the cylinder to the 1250 ml. graduation and shaken by hand for half a minute. The cap is then removed and the cylinder placed aside to sediment, noting the time.

The first sample to be removed corresponds to a settling velocity of 10 cm. in 4 mins. 48 secs. at 20° C. It is more convenient to use the long-stemmed pipette and to withdraw the sample from 28 cm. below the surface, the corresponding time of sedimentation being 13½ mins. at 20° C. Should the temperature be other than this standard temperature, the correct time of withdrawing the first pipette sample is shown in the third column of Table II. After the proper time has elapsed from the commencement of the sedimentation, the pipette, closed at the top with the forefinger, is passed through a hole in a sheet of cork and carefully lowered into the suspension until its tip is 28 cm. below the surface. A piece of thick walled rubber tubing on the lower stem of the pipette serves as a stop to indicate the correct depth if the pipette is always used in the same cylinder.

After filling the pipette, using continuous gentle suction as produced by the device figured on page 20 of Pamphlet 8, the 20 ml. of suspension are transferred to a weighed silica basin, evaporated on a water bath, dried at 105° C. in an electric oven until constant (generally overnight), cooled in a desiccator and weighed.

The second pipette fraction corresponds to a settling velocity of 10 cm. in 8 hours at 20° C. In order to allow the sedimentation to proceed overnight when there will be the least temperature fluctuation in an ordinary laboratory, one of two alternative depths is used in pipetting this second sample. If the average temperature during sedimentation is likely to be less than about 21° C. the second sample is pipetted from a depth of 22 cm. below the surface, the corresponding time being given in the fourth column of Table II. At the proper time, the pipette is lowered into the suspension and the 20 ml. sample withdrawn as before.

When the average temperature exceeds 21° C. the time of sedimentation for 22 cm. becomes too short for convenient use as an overnight sedimentation. When this is likely to be the case the cap is replaced on the cylinder after withdrawing the first pipette sample, and the suspension shaken until it is again uniform. It is then set aside to sediment for the correct time, as given in the fifth column of Table II., and the second sample pipetted from a depth of 28 cm. below the surface. Evaporate, dry and weigh as before.

* Experience with the hydrogen peroxide pre-treatment suggests that it is more economical to add the hydrogen peroxide to the soil and leave overnight before heating on the water bath. The soil organic matter is slowly attacked in the cold, and there is no wasteful decomposition of hydrogen peroxide due to the heating.

It is desirable that, after weighing the second pipette fraction in the oven dry condition, it be ignited in an electric muffle and reweighed.

The percentage of silt is given by the difference in weight between the first and second samples x $\frac{1250}{20}$ x $\frac{100}{25}$ = difference in weight x 250.

The percentage of clay is given by the weight of the second sample x 250.

After the second pipette sample has been removed, most of the suspension is siphoned off and the residue washed into a 500 ml. tall pyrex beaker as in the previous method. The fine sand is separated by repeated decantation. the height of water being 10 cm. and the time of sedimentation 4 mins. 48 secs. at 20° C. The second column of Table II. gives the appropriate time for other temperatures. Towards the end of the decantations the sand should be rubbed once or twice with a rubber pestle.

After its separation the fine sand is dried at 105° C. and weighed.

The coarse sand, retained on the 70 mesh sieve, is also weighed in the oven dry condition instead of the ignited. No separation is made of the 2 mm. to 1 mm. portion, formerly "fine gravel." (See, however, Section *e*.)

The results of the mechanical analysis should be recorded in the following form :—

Coarse sand.	Clay.
Fine sand.	Loss on acid treatment.
Silt.	Moisture.

The loss on ignition should be given separately.

Equipment for mechanical analysis.—The change to the International method has necessitated small changes in the sieves and pipettes used in the method. All the other apparatus is the same in both methods. The alterations in the sieves and pipettes are given below.

Sieves.—As previously mentioned, these should be of 70 mesh I.M.M. gauze instead of the 90 mesh formerly used.

Pipettes.—For the samples taken at 28 cm. below the surface the long stemmed pipettes as used formerly (41 cm. stem) are still used, but the lower stem is graduated at 28 cm. instead of 30 cm. from the tip. For the sample from 22 cm. below the surface a 20 ml. pipette, with lower stem 31 cm. long and marked at 22 cm. from the tip, has been used. The time of delivery of all pipettes should be between 25 and 30 seconds.

Two sets, each of 10 pipettes, with 41 cm. stems, and one set of 10 pipettes with 31 cm. stems are used.

(*d*) *The Effect of Temperature on Sedimentation.*—

If the temperature of the suspension differs from the standard temperature (20° C.), the time of sedimentation, or conversely, the depth of sampling, must be adjusted to allow for the change in viscosity of the water.

It has been found preferable to adjust the time of sampling rather than the depth, and Table II. shows the times for pipetting the first and second samples and also the time of decantation of the fine sand separation for temperatures between 8° and 32° C. The temperature coefficients used in these calculations are those given by Robinson (8) and Crowther (3), the value at 10° being 0·767 instead of 0·784 as previously given. (1, 6.)

TABLE II.

TIMES OF SEDIMENTATION AT DIFFERENT TEMPERATURES. INTERNATIONAL SYSTEM.

Temperature.	Fine Sand. Decantation.		Silt. First Pipette Sample.	Clay. Second Pipette Sample.	
Deg. C.	Depth 10 cm. Mins.	Secs.	Depth 28 cm. Mins.	(a) Depth 22 cm. Hrs.	(b) Depth 28 cm. Hrs.
8	6	40	$18\frac{3}{4}$	$24\frac{1}{2}$	..
9	6	30	18	$23\frac{3}{4}$	..
10	6	20	$17\frac{1}{2}$	23	..
11	6	10	17	$22\frac{1}{4}$	..
12	6	0	$16\frac{1}{2}$	$21\frac{3}{4}$	..
13	5	50	$16\frac{1}{4}$	$21\frac{1}{4}$	..
14	5	40	$15\frac{3}{4}$	$20\frac{1}{2}$	..
15	5	30	$15\frac{1}{4}$	20	..
16	5	20	15	$19\frac{1}{2}$	$24\frac{3}{4}$
17	5	10	$14\frac{1}{2}$	19	$24\frac{1}{4}$
18	5	0	$14\frac{1}{4}$	$18\frac{1}{2}$	$23\frac{1}{2}$
19	5	0	$13\frac{3}{4}$	18	23
20	4	48	$13\frac{1}{2}$	$17\frac{1}{2}$	$22\frac{1}{2}$
21	4	40	$13\frac{1}{4}$	$17\frac{1}{4}$	22
22	4	30	13	$16\frac{3}{4}$	$21\frac{1}{2}$
23	4	30	$12\frac{1}{2}$	..	21
24	4	20	$12\frac{1}{4}$	..	$20\frac{1}{2}$
25	4	15	12	..	20
26	4	10	$11\frac{3}{4}$	..	$19\frac{1}{2}$
27	4	5	$11\frac{1}{2}$	..	19
28	4	0	$11\frac{1}{4}$	..	$18\frac{1}{2}$
29	3	55	11	..	$18\frac{1}{4}$
30	3	50	$10\frac{3}{4}$	..	$17\frac{3}{4}$
31	3	45	$10\frac{1}{2}$	..	$17\frac{1}{2}$
32	3	40	$10\frac{1}{4}$	..	$17\frac{1}{4}$

It was expected that the application of the temperature correction to the settling times would result in considerable differences from previous uncorrected analyses. The temperatures at which the latter were obtained have not been recorded, but by choosing a number of analyses from the laboratory card index a considerable temperature range seems assured. Comparison of these analyses with those obtained by the use of corrected settling times shows that, on the whole, no serious errors are involved.

Joseph and Snow (4) have also noted that in soils examined by them the temperatures of sedimentation have had little effect on the percentages of clay obtained. Earlier analyses, without the temperature correction, can therefore be used, after the interpolation, for comparison with analyses now being made, without fear of serious error. However, in all the analyses recorded in this paper, the times of sedimentation have been corrected for temperature.

(e) *Transposition of Analyses from the former British System to the International System.*—

The alteration in the size limits of the various soil fractions and the expression of results on the oven dry, instead of ignited, basis brought about by the adoption of the International system would constitute a serious change if it were not possible to transpose results from one system to the other. Analyses can be so transposed, provided both sets of results are required on the same (oven dry or ignited) basis, by interpolation from summation curves in which the accumulated values for the successive fractions are plotted against the logarithms of the settling velocities. (Robinson (7)). However, since former analyses are given on an ignited basis and the International system requires results on an oven dry basis, a correction has to be made to allow for this difference. To determine whether a factor for such a correction could be generally applied, twenty-two soils were selected, covering a wide range of types, and these were analyzed according to both the British and International systems. All fractions were determined on both the ignited and the oven dry basis and the results are summarized below.

(i) *Clay.*—It will be seen from Table III. that the clay ignition losses lie, with one exception, between 8 and 19 per cent. of the clay fraction. If we make the assumption that the ignition loss is the same for all clays, a good approximation to the oven dry clay can be found. The mean loss is calculated by summing all the clay fractions and all the clay losses, and is found to be about 14 per cent. It is not sound to take as the mean loss the mean of the individual percentage losses of the fractions, as this would attach too much importance to large losses in small fractions, as for example in the case of soil No. 90A. Using the above value, and comparing the oven dry values so obtained with the experimentally determined figure, quite good agreement is observed. Even in the case of the exception mentioned above, soil No. 90A, the calculated value is sufficiently close to the experimental to be useful.

(ii) *Silt.*—Although the silt ignition losses vary considerably, the same assumption can be made as for the clays, and leads to a mean loss of 7 per cent., as shown in Table III.

The percentages calculated on this basis show fair agreement with the experimental figures, although not so good as in the case of the clays.

(iii) *Fine Sand and Coarse Sand.*—The ignition losses of these fractions are very small, and can be taken, with sufficient accuracy, as 0·5 per cent. of the fraction concerned.

TABLE III.

THE RELATION BETWEEN OVEN DRY AND IGNITED VALUES FOR INTERNATIONAL CLAY AND SILT.

Soil Number.	Clay.			Silt.		
	Ignited.	Oven Dry.	Difference of Ignited.	Ignited.	Oven Dry.	Difference of Ignited.
	%	%	%	%	%	%
14 ..	27·9	31·8	14	7·8	7·8	0
19 ..	5·8	6·9	19	2·4	2·5	4
21 ..	44·6	52·3	17	8·8	10·1	15
22 ..	53·3	61·6	16	3·4	3·6	6
27 ..	57·9	66·5	15	11·4	13·2	16
30 ..	29·5	33·0	12	..	..	..
32 ..	6·9	7·7	12	4·8	5·0	4
50A ..	49·9	56·8	14	7·7	7·6	−1
60 ..	4·5	5·3	18	7·3	8·1	11
90A ..	6·6	9·2	40	7·6	8·7	14
99 ..	23·1	26·0	13	39·7	40·6	2
100 ..	12·2	13·3	9	16·0	16·8	5
101 ..	50·1	55·5	11	6·6	8·0	21
103 ..	14·5	17·3	19	4·6	5·7	24
177 ..	8·6	9·7	13	12·5	13·4	7
277 ..	21·9	25·1	15	2·7	2·6	−4
278 ..	24·3	27·6	14	..	..	..
279 ..	15·4	18·0	17	2·4	3·3	37
790 ..	17·9	19·4	8	5·3	6·1	15
807 ..	38·1	42·1	10	..	..	..
843 ..	48·2	54·6	13	12·2	12·9	−2
U.65 ..	12·4	13·4	8	19·6	20·5	4

Weighted mean ratio $\frac{\text{oven dry}}{\text{ignited}}$ clay = 1·14

Weighted mean ratio $\frac{\text{oven dry}}{\text{ignited}}$ silt = 1·07

The summation curves of the 22 soils were plotted, using the ignited British figures, and values for the ignited International fractions were obtained by interpolation. In most cases these showed good agreement with the International ignited values found by analysis. In some cases, however, the coarse sand and fine sand fractions showed disagreement. This was found to be due to the true curve being much steeper than the British system analysis indicated. It seems desirable therefore to determine one or two intermediate sand fractions in such cases ; this can be done quite rapidly by means of sieves. The coarse sand does not always extend up to the 2 mm. limit, and it is then misleading to plot this fraction on this assumption. The use of two round hole sieves 0·5 mm. and 1·0 mm. respectively, suffices to determine roughly the upper limit of the coarse sand.

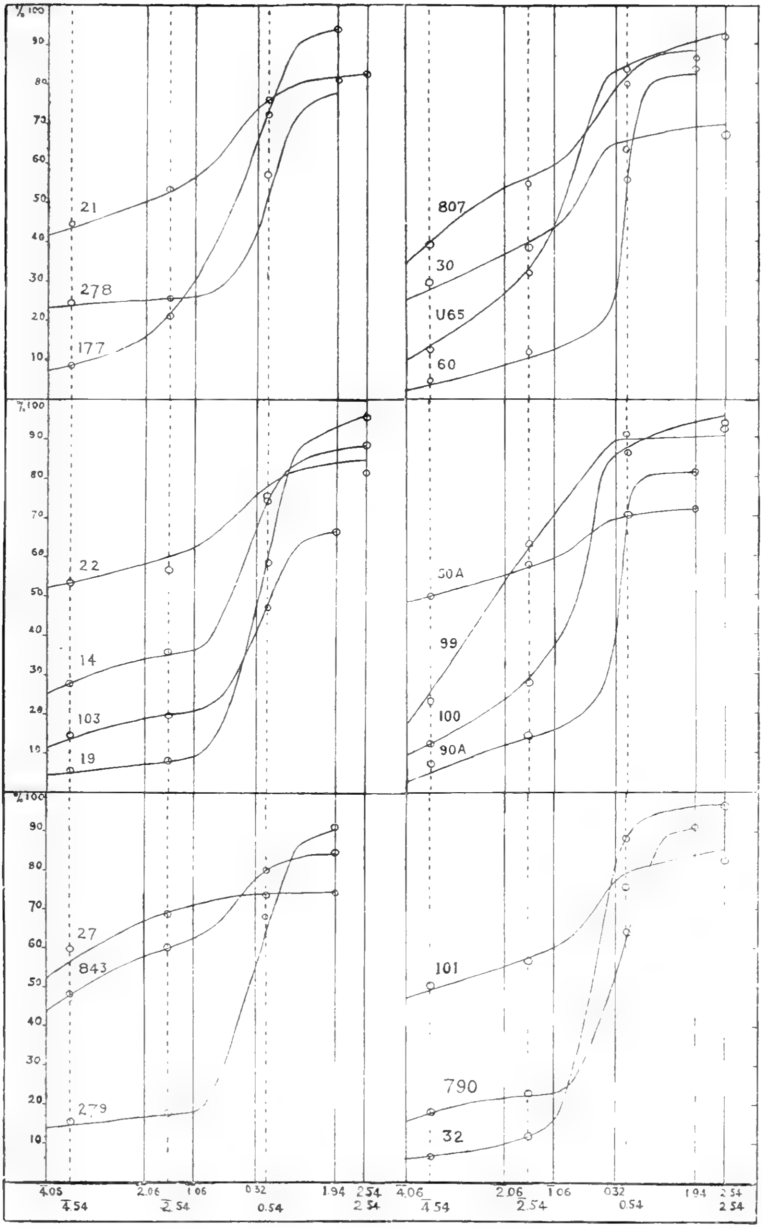

FIGURE I.—ILLUSTRATING THE METHOD OF INTERPOLATING RESULTS FROM THE FORMER BRITISH TO THE INTERNATIONAL SYSTEM.

The ordinates represent summation percentages, and the abscissae the logarithms of the settling velocities at 20° C. The solid vertical lines represent the limiting settling velocities at 20° C. of the fractions in the British system, and the dotted lines correspond to the fractions in the International system.

Having thus obtained the values of the different International fractions on an ignited basis, they can be converted to the oven dry basis with reasonable accuracy by multiplying by the factors given above, namely 1·14 for clay, 1·07 for silt, and 1·005 for fine and coarse sands. It is of interest to note that the ratios obtained by J. A. Prescott for Egyptian soils are 1·15, 1·11, and 1·05 for British clay, fine silt, and silt respectively.

Typical summation curves of some of the soils analysed are shown in Fig. 1. These illustrate the method of interpolation. The experimentally found International fractions on an ignited basis are indicated by circles, and it will be seen that they are close to the summation curves drawn from the values obtained by analysis according to the old British method. Table IV. shows some of the International analyses, and the agreement between the experimentally determined oven dry values and those obtained by interpolation from British values followed by correction to the oven dry basis is typical of most of the soils examined.

The soils which lead to difficulty are those having a fairly large coarse sand fraction. The shape of the curve near the upper limit then considerably affects the point at which the curve passes through the line representing the upper limit of the International fine sand. Curves 19 and 278 show this clearly. In certain soils the difficulty is accentuated to such an extent as to render accurate interpolation impossible for this fraction ; Curve 60 is such a case. Curves such as 22 and U 65 lend themselves readily to interpolation.

Generally speaking, interpolation is easy for the International clay and silt fractions.

Table IV.

Comparison of Interpolated and Observed International Analyses.

Soil Number.	14			27			99		
	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
Coarse Sand ..	14·5	14·6	13·7	0·4	0·4	0·3	0·9	0·9	1·0
Fine Sand ..	39·0	39·2	39·9	4·5	4·5	4·8	27·5	27·6	28·4
Silt	7·1	7·6	7·8	13·0	13·9	12·3	36·2	38·7	40·6
Clay	27·9	31·8	31·8	56·5	64·4	66·7	25·7	29·3	26·0
Soil Number.	278			279			807		
Coarse Sand ..	26·3	26·4	24·5	25·4	25·5	23·4	6·2	6·2	6·4
Fine Sand ..	25·9	26·0	31·3	47·5	47·7	50·2	25·5	25·6	25·4
Silt	1·8	1·9	2·0	2·7	2·9	3·3	16·7	17·9	18·4
Clay	23·8	27·1	27·6	14·6	16·6	18·0	39·8	45·4	43·1

(a) Interpolated values on ignited basis.
(b) Interpolated values corrected to oven dry basis.
(c) Observed values on oven dry basis.

3. The Use of an End Runner Grinding Mill in the Preparation of Soil Samples.

Before the laboratory investigation is commenced, the soil sample as taken from the field, has to be air dried and ground under such conditions as will not actually break down any of the ultimate particles. For this purpose, a mortar and wooden pestle is generally used, but it becomes very tedious for heavy clay soils.

An end runner mill fitted with an iron mortar and wooden pestle was tried, but it was found to have far too drastic an effect on some soils. In one case the coarse sand was reduced from 50·0 per cent. to 4·9 per cent., all the other fractions, especially the fine sand and silt, being correspondingly increased. This occurred even when there was no weight on the wooden pestle. The mill was driven at about 100 revolutions per minute by an electric motor.

To determine whether the actual grinding of the soil particles could be prevented, the mortar was specially lined with rubber.* Samples of six soils were then ground in the mill for several times as long as would normally be required. Sandy soils which would not usually require any grinding were included in the series, since, if the mill was still too drastic, this type of soil would show most change. No weight was placed on the wooden pestle during grinding, except in the case of heavy clay soils, and then the weight was as small as conveniently possible.

After grinding, mechanical analyses were made on all six soils and Table V. compares the results with the corresponding analysis of the same soil before grinding in the mill. The analyses were made before the International System was finally standardized in this laboratory.

TABLE V.

GIVING THE MECHANICAL ANALYSES OF SIX SOILS BEFORE AND AFTER GRINDING IN A RUBBER-LINED END RUNNER MILL.

(Results Expressed on Old British System.)

Soil Number	19		27		32		50A		90A		279	
Locality	Berri.		Mobilong.		Angaston.		Penola.		Mt. Gambier.		Pinnaroo.	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
	%	%	%	%	%	%	%	%	%	%	%	%
Coarse Sand ..	49·5	48·7	0·5	0·4	16·7	19·5	2·5	2·5	39·6	34·8	34·9	33·7
Fine Sand ..	38·3	39·7	2·5	2·5	65·2	62·5	9·7	9·5	25·8	32·0	37·2	38·7
Silt	1·1	1·0	4·9	4·3	5·3	5·1	4·4	5·0	4·1	4·2	1·4	1·1
Fine Silt ..	2·7	2·2	14·6	14·0	3·9	3·8	6·9	6·5	9·0	7·3	2·8	3·5
Clay	4·5	4·9	51·8	54·1	6·0	5·9	48·1	48·6	2·8	5·2	13·9	13·9
Loss on Acid Treatment	0·6	0·5	1·5	1·8	0·4	0·3	2·7	3·6	4·4	3·3	3·4	3·1
Loss on Ignition ..	1·8	1·9	14·4	14·8	1·8	1·8	11·5	11·8	11·6	10·9	4·0	4·1
Moisture ..	0·7	0·8	8·0	7·5	0·5	0·5	13·3	13·3	3·6	3·2	2·6	2·5
	99·2	99·7	98·2	99·4	99·8	99·4	99·1	100·8	100·9	100·9	100·2	100·6

(a) Mechanical analysis after hand grinding.
(b) Mechanical analysis after grinding in end runner mill.

* By arrangement with the Dunlop Rubber Company, Melbourne.

An examination of the table will show that excellent results were obtained after the mortar of the mill had been rubber lined, the analyses before and after grinding agreeing very closely, except for soil No. 90A. This sample represents a volcanic soil from Mt. Gambier and the percentage of fine sand has been increased due to the crushing of some of the coarse sand particles. This is perhaps to be expected in this type of soil since some of the sand particles are of a soft material that is easily broken down. In this soil the clay also shows a marked increase as a result of grinding. However, in the ordinary preparation of this sample, practically the whole of the soil would pass through the 2 mm. sieve without requiring any grinding in the mill.

The three soils, Nos. 19, 32, and 279 show that the rubber lined end runner mill can be used for sandy soils without fear of breaking down any of the ultimate soil particles. The analyses before and after grinding are in very good agreement throughout.

Soils Nos. 27 and 50A represent heavy clay soils, and here again there is practically no difference in the analyses before and after grinding.

It is thus seen that the rubber lined mill can be used for the preparation of most soil samples without altering the mechanical composition due to breaking down of the soil particles. The soil sample after grinding appears much finer than the corresponding sample prepared by hand, but this must be due to the greater crushing of all aggregate particles, since the analyses show conclusively that it is not due to a real grinding of the ultimate soil particles.

4. The Motor Dispersion Unit used in the Mechanical Analysis.

On page 15 of the previous pamphlet, No. 8, an alternative method of dispersion was given, a fan motor directly coupled to a nickel propeller being used. This method has now been fully tested on a large number of soils, and has been found to give results quite comparable with those obtained when the soil was dispersed by repeated rubbings with a rubber pestle. It is quicker than the hand rubbing method, and eliminates any personal error that might otherwise occur in the dispersion. The apparatus and method has been fully described previously (6) and is illustrated in Plate 1.

In Table VI. the dispersion of ten soils by the motor dispersion unit is compared with that obtained by the earlier method of rubbing with a rubber pestle. Only the values for silt, fine silt and clay are given, since the separation of the fine and coarse sands is the same in both methods. It will be seen that there is very good agreement throughout, differences greater than 1 per cent. occurring in only three instances.

TABLE VI.

DISPERSION OBTAINED BY THE MOTOR DISPERSION UNIT COMPARED WITH THAT OBTAINED BY HAND DISPERSION.

Soil Number.	19		21		22		27		32		50A		90A		99		177		277	
Locality.	Berri.		Mount Barker.		Mount Barker.		Mobi-long.		Angas-ton.		Penola.		Mount Gam-bier.		Spald-ing.		Kuitpo.		Pin-naroo.	
Old British Units.	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Silt	1·3	1·1	7·3	6·4	3·9	4·4	6·3	4·9	5·3	5·3	4·5	4·4	4·1	4·1	18·1	16·5	14·1	13·7	1·4	1·3
Fine Silt ..	2·0	2·7	9·0	8·5	5·8	6·1	14·6	14·6	3·7	3·9	8·5	6·9	8·4	9·0	36·3	36·4	8·7	9·0	3·3	3·2
Clay	5·6	4·5	41·9	41·6	52·5	52·1	50·9	51·8	6·3	6·0	47·3	48·1	3·6	2·8	17·7	17·4	7·7	7·1	19·7	20·3

(a) Soil dispersed by rubbing by hand with a rubber pestle.
(b) Soil dispersed in motor dispersion unit for fifteen minutes.

If the average value for the silt, fine silt and clay, as determined by hand rubbing, is called 100 per cent. then the average values as found when the motor dispersion is used, are 93·7 per cent., 100·0 per cent., and 99·4 per cent. respectively. The agreement in the fine silt and clay is seen to be particularly good, and shows that the motor dispersion unit is very efficient in securing dispersion. Possibly, experimental errors in pipetting the first samples account for some of the differences observed, since particles of this fraction have a high critical velocity.

Similar results to those given in Table VI. have been obtained with all the soils that have been tried. The motor dispersion unit has thus been shown to give satisfactory dispersion, and it is now being regularly used.

5. Summary.

Details are given of the alterations necessary to bring the method for the mechanical analysis of soils, as developed at the Waite Institute, into line with a recently adopted International method.

Tables are given showing the times of sedimentation for fine sand, silt, and clay at different temperatures.

A number of soils have been analysed according to the old and new standards, and the method of interpolation of results from one system to the other illustrated.

The average difference between the ignited and oven dry values of the silt and clay fractions of a number of soils has been found to be 7 per cent. and 14 per cent. respectively.

An end runner grinding mill, the mortar of which is lined with rubber, has been shown to be satisfactory for the preparatory grinding of soil samples.

Results are presented to show that a motor dispersion unit, which had been previously described, gives satisfactory dispersion for mechanical analysis.

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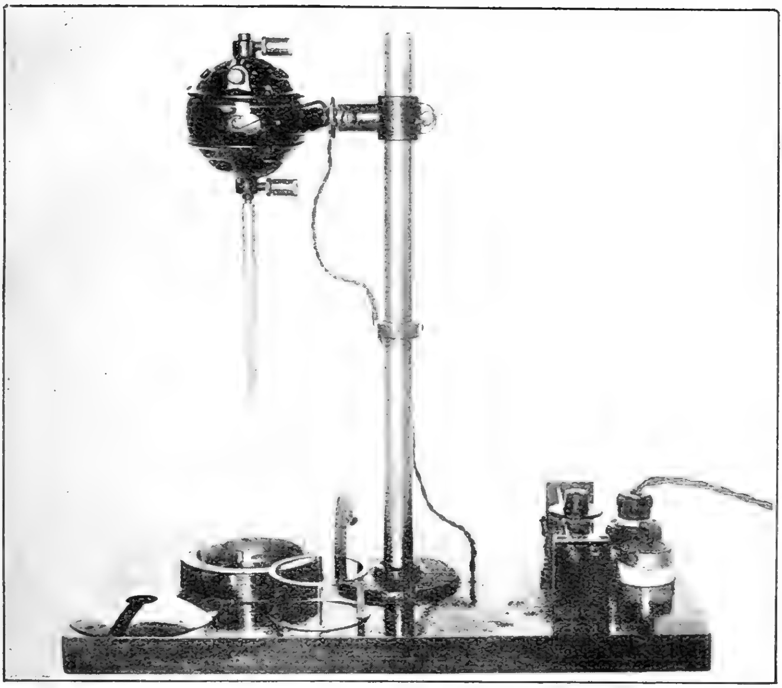

PLATE I.—THE MOTOR DISPERSION UNIT.

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COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

THE WORK OF THE DIVISION OF ECONOMIC BOTANY FOR THE YEAR 1928-29

By

B. T. DICKSON, B.A., Ph.D.
Chief of the Division

MELBOURNE 1929

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CONTENTS.

The Work of the Division of Economic Botany for the Year 1928-29.*

By B. T. Dickson, B.A., Ph.D., Chief of the Division.

In submitting this, the First Annual Report of the Division of Economic Botany, it is a pleasure to acknowledge the support of the Council, the courtesy and consideration of Headquarters and the loyal and willing co-operation of the Divisional Staff during the period of initiation of the work embodied in the Report.

The Report is presented in two parts, dealing respectively with a general outline of the programme of the Division, and with specific undertakings up to 30th June, 1929.

I. GENERAL.

1. Creation of Division and Personnel.

In pursuance of the general scheme of operations decided upon as being within the province of the Council, the importance of the field of investigations into the many and varied problems concerning crop and other plants rendered necessary the creation of a Division for that work. While the term "Plant Industry" more adequately envisages the field involved, it was decided that the Division should be known as that of "Economic Botany," and Professor B. T. Dickson, B.A., Ph.D., assumed charge as from 27th February, 1928. Temporary quarters in the Botany School were provided by arrangement with the authorities of the University of Sydney, whose constant courtesy and consideration have been much appreciated. Obviously, while in temporary quarters, the Division has been inevitably seriously handicapped in the prosecution of problems in spite of the utmost consideration on the part of the University. Nevertheless, satisfactory progress is recorded in the details of investigations to be noted later in this Report.

Inasmuch as the scope of work is varied, it was decided that certain definite sections should be initiated first, and that others should develop as a matter of growth. Consequently the section of plant pathology, by reason of the serious losses from plant diseases, was first organized by the appointment of a nucleus of staff, and investigations into certain problems were commenced. This was followed by the initiation of work in plant breeding, and arrangements are now in progress for the commencement of sections of plant introduction and agrostology. A serious handicap is the lack of a sufficiency of well-trained men in Australia to undertake the scientific investigations of the Division—a lack due not to any intellectual inferiority on the part of students in our universities, but to the few openings and rather meagre financial returns presented

* Typescript received 30th July, 1929.

in the past. It is hoped that this situation will gradually be remedied, but it will inevitably be some years yet before a fully concerted attack on some problems can be launched.

The present staff of the Division is as follows :—B. T. Dickson, B.A., Ph.D., Chief ; H. R. Angell, B.Sc.Agr., Ph.D., and W. M. Carne, F.L.S., Senior Plant Pathologists ; C. C. Brittlebank, Mycologist ; J. G. Bald, B.Agr.Sc., Assistant Plant Pathologist ; J. R. A. McMillan, M.Sc., Senior Plant Geneticist ; and T. B. Paltridge, B.Sc., Field Officer in Agrostology. In addition, W. V. Ludbrook, B.Agr.Sc., is a research student in plant pathology, and W. Bryden, M.Sc., in plant genetics, each working under the guidance of a senior officer and Dr. Dickson. Dr. Jean White-Haney is seconded from Headquarters for six months to the Division as a temporary officer for Noogoora burr investigations. Mr. H. A. Pittman, B.Agr.Sc., was an Assistant Plant Pathologist in the Division until 1st March, 1929, when he became Plant Pathologist for the Department of Agriculture of Western Australia.

In accordance with the announced policy of the Council, the Division will engage in such studies of plant problems as call for fundamental and long-time investigation, and which are of importance to more than one State of the Commonwealth. In these problems, the co-operation of the scientists in State Departments will be sought, and effect has already been given to such an arrangement, as in the case of studies in bitter pit of apples, spotted wilt of tomatoes, and water blister of pineapples.

In certain instances, the Division may be asked specifically to undertake an investigation, as illustrated by those on water blister of the pineapple, blue mould of tobacco, and Noogoora burr ; but even then, co-operation is desirable, certainly on some phases of the problems.

2. Projected Scope of Work.

In a first annual report, it is well to give an outline of the projected scope of the work, bearing in mind, however, the fact that modification in detail may be necessary as the Division develops.

A matter of prime importance is that of improvement in our present crop plants, and such improvement may be in yield or quality, or both. One of the chief factors in reducing yield is that of disease, and consequently efforts must be made to prevent or minimize this loss. Usually, it is only when disease occurs in epidemic severity that definite attention is focussed upon it and estimates of losses are available. Every year in every crop, however, a toll is taken which is generally regarded as reaching about 10 per cent. of the crop, but the general distribution of the loss, and in many cases the obscured occurrence and results, tend to a false impression of the health of the crop. A loss of £50,000 per annum is estimated as a result of bitter pit in apples, and £7,500 per annum by water blister of pineapples, two diseases with which we are now working. "Blue mould" of tobacco is so serious in some years that almost total loss occurs, and that disease, coupled with "aroma," constitute limiting factors in the development of supplies for the Australian market, which is worth £2,000,000 per annum. Rust in wheat gave rise to a loss of

£2,000,000 in New South Wales in 1916, the year when Canada lost 100,000,000 bushels through stem rust. In 1924 at Cowra it was found that Waratah wheat gave 48 bushels per acre when free from "take-all," and only 11 bushels per acre when diseased. Bunchy top of bananas and spotted wilt of tomatoes are limiting factors with those crops.

The reduction in loss may be brought about by actual control of the disease, by seed selection, seed treatment, spraying or other methods, or by the selection and breeding of resistant or immune types.

Yield may be improved by the breeding of higher yielding types, even if the question of disease does not enter. Farrar's development of Federation and other wheats in Australia, and Saunders' work on Marquis wheat in Canada illustrate this, the former being worth many hundred thousand pounds to wheat growers in Australia. Another phase of possible improvement in yield is that involved in nutrition, and one has only to think of the influence of superphosphate on wheat to realize what an important part nutrition plays. Much has yet to be done with respect to deficiencies in nutrition and the role of infinitesimals or minimals.

Quality is susceptible of improvement by selection and breeding, and nutrition studies may throw light here also. A wide, yet highly important, field in this work is that dealing with pasture grasses and plants, both native and introduced. It must be borne in mind that there are no short cuts in these investigations, and usually they require several years of patient work before promising results may be expected. Grading for market quality falls outside the scope of the divisional programme.

In order clearly to visualize the situation regarding any problem in the above-mentioned categories, it is necessary to know as fully as possible what the present condition is with respect to the occurrence and severity of disease, the possibility of yield and quality improvement, and so on. This calls for surveys, and of these surveys those of plant diseases and of pastures are the most important.

The field of crop improvement so far dealt with has been concerned with present crop plants, but it is obvious that most of these plants have been introduced into Australia. That the field of plant introduction is not exhausted of its potentialities is certain, and efforts will be made to find, test, and introduce valuable additions for the benefit of the pastoralist and agriculturist. The introduction of subterranean clover (*Trifolium subterraneum*), Kikuyu grass (*Pennisetum clandestinum*), and lucerne (*Medicago sativa*), are illustrations of what has been done in the past in this respect. The United States Office of Foreign Seed and Plant Introduction of the Department of Agriculture has tested over 65,000 species and varieties of plants since its inception, and many valuable additions to American agriculture have been selected. It is of interest to Australia to note that in Oregon and Idaho half a million acres are sown to Federation and Hard Federation wheats, and also that recently an aeroplane expedition by U.S.A. agriculturists to New Guinea resulted in the finding of over one hundred varieties of sugar cane, many of which were apparently resistant to mosaic disease.

In order to safeguard against undesirable introductions, of which this continent already has some outstanding examples, e.g., prickly pear and Noogoora burr, studies will be made under quarantine conditions by arrangement with the Federal Department of Health, and only after rigid tests will releases be allowed. The variety of climates from which plants come, and for which they will be suited, will make it necessary to arrange for plant introduction gardens. At present it is contemplated to arrange for one suitable for cool climate grasses, &c., probably in Tasmania, one suitable for warmer climate plants, probably in Queensland, and also to use the glasshouses and experimental plots at Canberra.

Yet another source of loss, either in the crop itself or in the depreciation of agricultural lands, is the presence of weeds. In the former case, it calls for the use of clean seed and of proper cultural operations, but in the latter the problem is more difficult. The infestations by prickly pear, Noogoora burr, Bathurst burr, hoary cress, St. John's wort, &c., are cases in point. Prickly pear is being combated by attack from several angles, and there is now distinct hope that by the agency of insects, aided by fungi and bacteria, a satisfactory measure of control will be established. It is too much to hope for unqualified success in every case, but each pest plant will be investigated and efforts made to ascertain possible control measures. To this end, co-operative measures or co-ordinated studies between this Division, as that concerned with plants, and the Division of Economic Entomology are projected.

Finally, representative specimens of each plant or disease studied, each plant introduced as desirable or destroyed as a pest, will be recorded and preserved in suitable condition. This involves the establishment of an herbarium, which in course of time should accumulate a representative Australian collection. To this may be added representative specimens from State collections, so that in course of time a National Herbarium may become a fact.

The following tabulated outline indicates the proposed programme of the Division :—

Proposed Programme of Division.

A.—Improvement of Present Crops—

1. Improvement in yield—
   - (*a*) Reduction of toll taken by diseases—
     - (i) By control by spraying, &c.—Section of Plant Pathology.
     - (ii) By selecting and developing resistant types.—Sections of Plant Pathology and of Plant Breeding.
   - (*b*) Breeding higher-yielding types—Sections of Plant Breeding and Agrostology. (Suited to climatic zones, &c.)
   - (*c*) Balanced nutritional requirements—Section of Plant Nutrition or Physiology.

2. Improvement in quality—

   (*a*) Selection and breeding of better types.—Section of Plant Breeding and Agrostology.

   (*b*) Properly-balanced requirements during crop development—Section of Plant Nutrition (in co-operation with Divisions of Animal Nutrition and Soils).

B.—Improvement by Introductions.—

(*a*) Exploration and exchange.—Section of Plant Introduction (and other Sections as occasion offers).

(*b*) Testing introductions—

   (i) For disease, &c.—Section of Plant Pathology and Division of Economic Entomology.

   (ii) For agricultural value—Sections of Plant Introduction and Agrostology.

C.—Control of Weeds—

(*a*) Studies of weeds as to distribution, &c.—Section of Noxious Weeds Control.

(*b*) Control investigations.—Sections of Noxious Weeds Control, Plant Pathology, and Nutrition, co-operating with Division of Economic Entomology.

D.—Surveys—

(*a*) Plant disease and mycological.—Section of Plant Pathology.

(*b*) Pastures and pasture plants.—Sections of Agrostology and Nutrition.

(*c*) Weeds—as to extent, &c.—Section of Noxious Weeds Control.

E.—Herbarium Collections—

(*a*) Plant disease and mycological specimens—Sections of Plant Pathology and Herbarium.

(*b*) Grasses and forage plants.—Sections of Agrostology and Herbarium.

(*c*) Economic plants, flora generally.—Herbarium Section.

At present, work is in progress in the sections of Plant Pathology, Plant Breeding, Plant Introduction, Agrostology, Noxious Weeds Control, and Herbarium, although under the considerable handicap of lack of adequate facilities and staff.

In Plant Pathology, bitter pit, cork, water-core and internal breakdown of apples ; blue mould, phoma stem-rot and anthracnose of tobacco ; spotted wilt of tomatoes, and water blister of pineapples, are under investigation. An outbreak of moulds in sultanas was looked into and cleared up, and reports have been made on leaf spot of bananas and on the mycological factor in prickly pear control. Concerning the latter, the Division is maintaining, on behalf of the Commonwealth Prickly Pear

Board, some 250 pure cultures of organisms isolated from diseased prickly pear in U.S.A. by Mr. Lewcock. In addition to those from prickly pear, pure cultures of over 300 other fungi and bacteria are being maintained as the basis of a pure culture collection for investigational purposes. A beginning has been made in organizing a complete record of the occurrence and severity of plant diseases in the Commonwealth, and this will develop into a Plant Disease Survey to be maintained by co-operative effort for the use of investigators working on disease problems.

In the Section of Plant Breeding, no specific investigation has yet been initiated because of the recent appointment of the Senior Geneticist, and the lack of facilities for laying out work at the time. Now, however, an area of approximately 3 acres has been fenced in, partly cultivated, and water laid on. Some 300 varieties or strains of wheat, 30 of barley, and 20 of oats from different sources have been planted, and 200 strains of maize are to be planted as soon as danger of frost is over. This small area is merely sufficient to carry over the essential material, and it will be necessary to obtain an area of between 50 and 100 acres of suitable land as near as possible to Canberra, even to cope with immediate developments in breeding work.

The Section of Plant Introduction is only now being initiated, but in the meantime Dr. Dickson has communicated with colleagues in various countries with a view to the organization of exchange facilities. Some material has already been received, including grasses, wheats, and also a small sample of seed of *Solanum sanitwongsei*, the fruit of which is reputed to be a palliative for diabetes. The closest touch will be maintained between the sections of Plant Introduction and Agrostology, in view of the importance of pasture grasses and plants to the basic industry of the country. Arrangements regarding quarantine conditions have been concluded between the Department of Health and the Council.

The importance of grasses and other pasture plants is realized when it is recalled that over half of the exports of Australia is made up of wool and other animal products, all of which originate from food plants. Pasture improvement has been, and is, a matter of fact with many leading pastoralists, but there is still room for investigation into agrostological problems in the differing climatic zones. Work is in progress at Koonamore, South Australia, where attention is being focussed on the possibility of regeneration of eaten-out areas. This was initiated by Professor T. G. B. Osborn while at Adelaide University, and is now carried on as a co-operative project between the University of Adelaide, C.S.I.R., and Professor Osborn, as noted below. It is planned that the Division shall co-operate with the Waite Agricultural Research Institute in determining methods of technique suitable to agrostological surveys, and to that end, it is anticipated that at least two officers will spend a year or more at the Waite Institute.

In the Section of Noxious Weeds Control, there are unfortunately many problems and but few workers. Furthermore, in spite of the present promising possibilities in prickly pear control, resulting from years of patient effort, it must be borne in mind that because weeds are weeds they are not easily eradicated. In any work undertaken, close co-operation with the Division of Economic Entomology will be a matter of course. At present Noogoora burr is being investigated to ascertain its economic importance, its life history and distribution, and also to determine whether any insect or fungal pests attack it in its natural state. Noogoora burr belongs to the cockleburs, which are Xanthiums, and it has been generally known botanically as *Xanthium strumarium*. A certain amount of doubt attaches to this name, and Dr. Dickson has submitted specimens to authorities at Kew and Washington for determination. Interest is aroused in Scotland by the occurrence of a disease of bracken, and this is being inquired into by the Chief of the Division. By the kindness of the Scottish investigators, a pure culture of the organism has been received and tests under controlled conditions are planned.

At present, the collection of material for herbarium purposes is strictly limited because of lack of a place in which it may be suitably preserved. Arrangements have been made for a collection of Tasmanian grasses and herbage plants, and gradually it is hoped to build up collections of Commonwealth character.

As pointed out above, the Division has been partly accommodated since February, 1928, in the Botany School, by the kindness of the University of Sydney, and grateful acknowledgment is made for many courtesies freely extended during this occupancy. Here are to be found Divisional headquarters and part of the Section of Plant Pathology. The Plant Disease Survey work is in progress at C.S.I.R. headquarters in Melbourne. The work on bitter pit is centred at present in Perth, Western Australia, where scanty accommodation is available but freely given. The Plant Breeding Section is at Canberra in temporary quarters in Civic Centre. Naturally under such conditions there is a lack of adequate office and laboratory accommodation. Glasshouses with temperature control equipment, &c., are not available, and experimental plots cannot be laid down except under permanent occupation. It is most important that suitable facilities be provided as soon as feasible, and it is hoped that by the time the next annual report is being prepared, the Division will be occupying its own quarters.

3. Relations with other Bodies.

Before concluding this part of the Report mention should be made of relations with other bodies.

1. *Merbein Research Station.*—The research work of this station having to do mainly with vines under irrigation, and therefore being concerned jointly with plant and soil problems, has been placed under the control of a committee consisting of Dr. B. T. Dickson, Chief of the Division of Economic Botany (Chairman), Professor J. A. Prescott, Chief of the Division of Soils, and Professor T. G. B. Osborn, University Professor of Botany, Sydney.

2. *Commonwealth Prickly Pear Board.*—In view of the fact that certain fungi and bacteria affect prickly pears, and that disease, alone or in combination with insects, may be a factor in control, Dr. Dickson has been asked to act in an advisory capacity on mycological matters.

3. *Australian Tobacco Investigations.*—Arrangements have been made whereby Mr C. M. Slagg, Director of Tobacco Investigations for the Australian Tobacco Investigation, and Dr. B. T. Dickson shall constitute a Research Committee responsible to the Executive of the Australian Tobacco Investigation for the organization and carrying out of research work in tobacco aroma and "blue mould."

4. *Poison Plants Investigations.*—The Chief of the Division of Economic Botany is a member of the Commonwealth Poison Plants Committee, which is investigating the plants actually or reputedly poisonous to stock in Australia.

4. Publications of Division.

The following is a list of publications by members of the staff to date :—

1. Preliminary note concerning the transmission of "spotted wilt" by an insect vector (*Thrips tabaci* Lind.) H. A. Pittman, *Jour. Council Sc. Ind. Res.* 1 : (1927), pp. 74–77.

2 Dusting and spraying experiments for the control of "spotted wilt" of tomatoes. G. Samuel and H. A. Pittman, *Proc. Aust. Assoc. Adv. Sc.* 19 : (1928), pp. 588–590

3. Leaf spot of banana in Southern Queensland. B. T. Dickson, *Q. Agric. Jour.* 30 : (1928), pp. 455–457.

4. Notes on certain disorders of Cleopatra apples. W. M. Carne, H. A. Pittman, and H. G. Elliott. *Jour. Council Sc. Ind. Res.* 2 : (1929), pp. 49–52.

5. Studies concerning the so-called bitter pit of apples in Australia, with special reference to the variety Cleopatra. W. M. Carne, H. A. Pittman, and H. G. Elliott. Council for Scientific and Industrial Research, Bulletin 41 : (1929), 101 pp.

6. Division of Economic Botany : Some present activities. (From Progress Report of Chief of the Division), *Jour. Council Sc. Ind. Res.* 2. (1929), pp.94–97.

II. SPECIFIC INVESTIGATIONS.

1. Mould in Sultanas.

During April and May, 1928, a considerable development of moulds in the Nyah district threatened heavy loss in the dried fruits industry. Moulds are present to a limited extent every season when rains fall at the time of ripening of the fruit, but give rise to no concern. Owing, however, to heavy rains, much more was present this season and the pack was affected.

At the time of my visit in company with Mr. A. V. Lyon, Officer in Charge of the Commonwealth Research Station, Merbein, and Mr A. Lochhead. of the Dried Fruits Board, 5 tons of fruit had already been condemned by inspectors as unfit for export out of 4,000 tons of fruit in the district. Four large packing plants were visited ; one only was relatively free from moulds, and that because infected fruit was refused entry to the packing plant. Examination of fruit from boxes taken at random showed the presence of various moulds which were determined later. Sometimes single berries were affected, but more often the mouldy fruit was in clumps of varying size which were easily noticed when a box was turned out. Infection may have occurred while the fruit was still on the vines, and this is probably the case with attack by *Botrytis* sp. Further spread or new infections may arise in fruit on the racks, especially under humid conditions. *Penicillium* is commonly found on injured rack fruit. Wherever it may have arisen it was then in the boxes in much greater quantity than it should have been.

Laboratory studies of the moulds showed that the following fungi were present in the boxes of fruit :—

Botrytis cinerea, Penicillium sp., *Aspergillus niger, Aspergillus glaucus. Rhizopus nigricans*, and *Mucor racemosus.*

Moulds of this type develop rapidly under humid conditions and they are able to attack ripe or ripening fruit. That they are not confined to Australia is evidenced by reports of *Botrytis cinerea*, *Penicillium* sp., *Rhizopus nigricans* and *Aspergillus niger* on grapes for export from South Africa and of *Botrytis cinerea* and *Penicillium glaucum* on grapes in Tunis.

In the boxes examined, *Botrytis cinerea* and *Penicillium* sp. were most common, *Aspergillus glaucus, Mucor racemosus, Aspergillus niger*, and *Rhizopus nigricans* occurring in that order of importance. By experimental tests, it was found that heating moist sultanas inoculated with the organisms for one to three hours at 145° F. checked the growth of the fungi and did not appear to injure the fruit.

Mr. Lyon undertook to test the feasibility of washing, dehydrating for three hours at 145° F., and regrading representative boxes of fruit. with the result that a very marked improvement was demonstrated not only in the reduction of mouldy sultanas but in general appearance. No new growth of mould was observed in treated boxes two weeks after treatment, whereas new growth was readily observable in control boxes.

Recommendations following on this investigation are that :—

1. Growers should discard diseased fruit at picking or when spreading on racks.
2. Drying should be thorough and the fruit watched for mould if humid weather occurs.
3. Packing houses should wash and dehydrate fruit when mould is likely to develop. If this were a regular practice, the pack would most likely be more uniform and it would certainly be cleaner, thus enhancing Australia's reputation for dried fruits. The dehydration recommended is at 145° F. for three hours.
4. All debris, waste, and condemned fruit is a source of infection in the packing plant itself and should be removed from the packing sheds.

2. Leaf Spot of Bananas.

At the request of the Government of Queensland, the Chief of the Division of Economic Botany was asked to visit the banana-growing areas of southern Queensland in order to advise on leaf spot of bananas. This disease was causing considerable perturbation among growers because of the severity of attack during 1928, although undoubtedly it has been present in plantations for a number of years. Visits were made to representative Cavendish plantations in seventeen districts between 22nd June and 3rd July, 1928, and in every plantation the disease was present. Where trash had been removed and where plants were growing on well-drained, sheltered slopes, leaf spot was not serious, but in most cases it had spread to the young non-bearing plantations. During the tour it was evident that there were a number of abandoned plantations which constituted a menace to newer areas in the vicinity.

As the name indicates, the chief symptom of the disease is the spotting of the leaves. The lower leaves are affected first, the number of spots appearing depending on the conditions for infection in the plantation. If there is an abundance of diseased foliage and rains are frequent, there is also an abundance of infection, and it appears as if the disease gradually gets up a momentum so that there is a serious increase in its severity, as was in the case in 1928.

The middle of each rather oval spot dies and becomes somewhat ashy-brown or grey in colour, and later a fungus develops its spore-bearing bodies in that dead tissue. From these small black fungal bodies, many thousands of spores are spread during continued wet or muggy weather. Around the spots, the leaf-blade turns yellow, later becoming brown and dying. The coalescence of such areas may involve most or all of the leaf.

Gradually the spot invasion reaches the upper leaves, those below being now dead and hanging down against the stem. It was a common sight to see plants with but three living leaves left at the growing point, and when the bunch of fruit is maturing, it needs all the foliage possible, since it draws upon the leaves for its starch. In some cases, the bunch was developing sufficiently fast and was already near enough shipping maturity that it would just ripen, but much more frequently it was just reaching that stage of maturity when the demand on the few remaining leaves was heaviest. At this time, they also became infected with leaf spot and rapidly succumbed, so that the bunch could not mature.

The organism causing the disease (*Cercospora* sp.) is not a strong parasite, and, in order to affect the plants seriously, the conditions must be such that plants are weakened or debilitated. Cold, wet weather, unsuitable situation, poorly-drained soil, and poor cultural practices give a set of circumstances definitely favorable to the fungus and enabling it to assume epidemic proportions. That the trouble is seasonable is evidenced by its relative non-occurrence in summer, but growers should remember that the organism is still present and alive. Until more is known about the organism causing the disease, recommendations are based on hygienic precautions. Trash should be removed and destroyed and care taken in selecting clean suckers for new plantings. Old abandoned plantations should be destroyed, because they may be sources of disease.

Mr. J. H Simmonds, of the Queensland Department of Agriculture, is making a careful study of the disease.

3. Bitter Pit and Associated Diseases of Apples.

Bitter pit has been for many years, and still is, the major cause of wastage in exported Australian apples. Investigations, since 1892, have indicated that it is not of parasitic origin but that it belongs in the physiological diseases. Preliminary experiments in 1925 and 1927, and a study of the literature, suggested that the disease might be due to immaturity at picking time. The main lines of work have been :—

1. A comparative study of bitter pit lesions on stored fruit with those of the disease known as bitter pit occurring in fruit on the trees.
2. A comparative study of susceptible and non-susceptible varieties.
3. Attempts to find some method of determining maturity.
4. Picking and storage tests to determine the effect of varying maturity at picking time.
5. Incidental studies of other diseases of apples met with in the investigations.
6. A study of the relation of pit and other diseases to the general problems of the industry.

The work has been conducted by Mr. W. M. Carne, now a Senior Plant Pathologist, C.S.I.R., assisted (part time) by Messrs. Pittman and Elliott of the Plant Pathology Branch, Western Australian Department of Agriculture. The Department of Agriculture has willingly provided such office, laboratory, and library facilities as are available, but these are distinctly limited by the fact that the Department itself is sadly lacking in necessary accommodation.

The work done during 1928 and published in C.S.I.R. Bulletin 41 demonstrated :—

1. That the so-called pit developed on fruit while on the tree is cork and not bitter pit.
2. That pit is the result of picking apples before they have reached a certain stage of maturity.
3. That a simple iodine test for starch is a guide to maturity.
4. That bitter pit may be avoided by picking apples after they have arrived at a stage of maturity at which they are no longer susceptible.

During 1929, the work has been developed on the following lines :

1. Confirmation of the conclusions arrived at in 1928 and noted above.

2. Further inquiry into the causes of cork, breakdown, water-core, scald, &c., with a view to finding methods of controlling these diseases.
3. A study of the export industry, particularly in regard to the defects affecting sales and competition with other countries, and the problems arising out of later picking for pit control.

The work has not been completed, as storage tests will not be finished until October, and it is not considered desirable at the present stage to detail the conclusions reached. A new form of breakdown has been recognized and its control demonstrated. In regard to cork, interesting data relative to fruit acidity and fruit and leaf-sap pressures have been collected, which will probably aid in the solution of this problem. Rather definite conclusions have been arrived at as to the cause of one form of cork and of water core.

In reference to bitter pit, some very suggestive data in support of the theory put forward last year have been obtained. Further, it has been shown that there are at least two types of apple varieties on the basis of their liability to bitter pit at different storage temperatures.

On one section of the work, however, it is possible and desirable to make very definite statements. Our study, based largely on reports from Europe, of the apple export industry has shown that it is not in a healthy condition. The quality and condition of Australian fruit on arrival in England is not generally satisfactory and complaints are much more frequent than praise. The shipments from the different States vary in market value, those from Western Australia being in general best. This is principally due to the fact that the fruit in that State is the earliest to mature. That the low prices obtained are not due so much to weak markets, but rather to the poor quality and condition of our fruit, is shown by the growth of the competition from New Zealand and Chili, and these countries are securing better prices on the same market. Indeed, our failure to compete successfully with them shows that there is a danger of Australia being forced out of the European market unless there is some very definite improvement in our fruit in the near future.

The three principal defects of Australian apples in Europe are immaturity, bitter pit, and breakdown associated with over-maturity. As we demonstrated in 1928, and have confirmed beyond all doubt this year, bitter pit is definitely associated with immaturity. It follows therefore that the principal causes of wastage are immaturity and over-maturity, and a most important phase of the problem of wastage reduction is that of recognizing the correct maturity for picking. Further, we have found that the iodine test is an effective guide to picking maturity. The way has been opened for an immediate and much-needed improvement in the industry. Admittedly, varietal and seasonal differences require that each variety shall be picked according to the season and to varietal susceptibility to pit, breakdown, &c. Nevertheless, the general principle holds good for all apples, that later picking is essential for the elimination of immaturity and bitter pit, and a shorter picking season to avoid over-maturity. Local details must be worked out locally—a function of the Governments of the several interested States. In any case there is nothing to prevent at least a partial application next season of the principle of picking according to maturity.

The foregoing statements are so emphatic that supporting evidence is necessary. This is given briefly as under :—

1. All tests, whether in Australia or America, of picking and storing apples at different stages of maturity, have resulted in a decrease in pit development as the fruit was picked in a more mature condition. This has been shown in various years and places to be true for Cox's Orange Pippin, Ribston Pippin, Cleopatra, Dunn's, Jonathan, Granny Smith, Gravenstein and Annie Elizabeth. It has been shown for Cleopatra to apply as well in years of light crops as in those of heavy crops; for Jonathan, to apply in America as well as in Australia. No tests to our knowledge have ever given contrary results.

2. Secondly, by picking immature and matured apples on the basis of maturity as shown by the iodine test, we have obtained pitted and non-pitted apples respectively after storage. Apples picked when over-mature for picking on the basis of the iodine test gave over-mature apples in storage.

3. By examination of the earlier shipments of fruit leaving Western Australia this season, we were able, on the basis of the iodine test and a knowledge of the type of fruit shipped, to make predictions which were in complete conformity with European brokers' reports some six to eight weeks later. It should be pointed out that the condition of the fruit determines pit liability, as well as maturity. The large puffy fruit common in a season of light crops is very subject to both pit and breakdown. So short is the time of suitable picking maturity for such fruits that their export should be discouraged.

4. Lastly, on our advice some 800 cases—mainly of Cox's Orange Pippins—were rejected for immaturity from the first shipment (a small one) leaving Western Australia this year. This rejection was based on the iodine test* and was contrary to the opinion of both shipping agents and fruit inspectors. To support a claim for compensation for the rejection of reputedly prime fruit, a portion of the rejected lots was cold stored by the agents, to be opened on the arrival of the vessel in England. This was duly done. When opened the fruit was found to be badly pitted, already showing evidence of breakdown, and practically unsaleable. Much of the fruit was literally covered with pit spots. Examination showed that the percentage of affected apples varied from 55 in 2-in. to 97 in $2\frac{3}{4}$-in. sizes.

* The iodine test is not advised for general inspection work on wharfs, though it may be used as a valuable aid in certain circumstances. Its principal value is to determine maturity for picking.

It is claimed that an immediate and much-needed improvement can be obtained in our exported apples by picking them on a basis of maturity. It is admitted that this complete change in picking methods cannot be brought about suddenly, but it is obvious that a reduction in the amount of immaturity, bitter pit, and breakdown may be obtained next season by those controlling the industry.

During the 1930 season, it is proposed to concentrate particularly on the cork problem, with further incidental studies on water core, &c. Further attention will be given to the relation of storage temperatures to pit development to check results of this season's work. It is also intended to initiate preliminary experiments in regard to the picking of pears for export, this fruit being much more subject to wastage than apples, a factor which limits its export from Australia.

4. Spotted Wilt of Tomatoes.

The investigation of the "spotted wilt" disease of tomatoes was one of the first projects to be undertaken by the C.S.I.R., owing to the extreme severity of the disease and the general demand from growers for a complete investigation of the trouble. The disease is by far the most serious with which the tomato grower has to contend. In epidemic seasons it may destroy the entire crop over considerable areas, even with the larger growers who plant 10,000 or more plants. Within recent years, it has also appeared in tomato glass-houses, and it is rapidly becoming a serious problem to this more expensive industry. At the time the investigation commenced (October, 1926), nothing was known of the disease beyond the fact that it appeared to be of the nature of a virus disease, and the way in which it spread with such extraordinary rapidity remained unexplained.

Efforts were concentrated first on determining whether some insect was the carrier of the disease, and after a number had been tested with negative results it was discovered that a species of thrips, known as *Frankliniella insularis*, is the insect which normally spreads the virus, at least in South Australia. This thrips has also been found in New South Wales, at Bendigo in Victoria, and in Western Australia, but not yet near Melbourne, where spotted wilt of tomatoes is often severe. The insect vector in the vicinity of Melbourne has still to be determined, therefore, and the plans for carrying this out are mentioned below.

Concurrently with the work on the determination of the insect vector, experiments on control have been carried out by spraying, dusting, and fumigating, and cross-breeding work has been commenced with the aim of developing, if possible, a variety of tomato resistant to the disease. Preliminary experimental work has been carried out to determine certain relations between the virus and the thrips which carries it, and also what other plants than the tomato may harbour the disease—all of which points may have a bearing upon the development of the best control measures.

The investigation to date has been carried out at the Waite Agricultural Research Institute in South Australia. At the time the work was commenced, the Division of Economic Botany had not been established.

Since the Waite Institute had just been opened, and since it was situated within easy reach of extensive outdoor and glasshouse tomato areas which suffered severely from spotted wilt, it was considered the most suitable locality. An arrangement was entered into between the C.S.I.R. and the University of Adelaide whereby the Plant Pathologist, Mr. G. Samuel, M.Sc., at the Waite Institute should take charge of the investigation and be supplied with an Assistant Plant Pathologist, now Mr. J. G. Bald, B.Agr.Sc., of the Division of Economic Botany, and the necessary equipment by the C.S.I.R. The main item of equipment required was an insect-proof glasshouse, which was completed in May, 1927, and which was described in an article in the *Journal of the Council for Scientific and Industrial Research*, Vol. 1 : (1928), pp. 273–274, Pls. 1 and 2.

The information obtained during last season's work on the insect vector, *Frankliniella insularis*, will prove very valuable in planning further experiments on control. Since this thrips has been found to be a widespread inhabitant of both cultivated and wild flowers, the control of spotted wilt in outdoor tomatoes may prove to be particularly difficult unless a resistant variety can be bred. On the other hand, methods of control for commercial glasshouses should be able to be developed. based upon exclusion of the insect right from the seedbed stage, rather than on eradication when once it is in the glasshouses.

Experimental work is now being carried out to determine whether certain weeds or other plants found near tomato fields can harbour the virus of the disease. The question of the insect vector of the disease in the vicinity of Melbourne has also to be cleared up. This can best be done by a worker stationed on the spot, and arrangements are being made whereby the Assistant Plant Pathologist, who has been working hitherto at Adelaide, will be transferred for a period to Melbourne to work in co-operation with the Plant Pathologist of the Victorian Department of Agriculture in an endeavour to clear up this side of the problem. It may also be found advisable to obtain the co-operation of an entomologist to work on matters connected with the life-history of the vector thrips, in order to provide adequate information on which to develop methods of control. Such questions as the source of thrips invasion of tomato glasshouses, whether from seedlings from the seed-beds, from the outside through cracks or holes in the glass, or from the soil as a carry-over from the previous season, come within the province of the entomologist rather than the plant pathologist.

The work done to date has been written up as a bulletin which is now in course of publication. The information which it gives on the manner of spread of the disease will enable careful tomato growers to do more towards controlling spotted wilt than was possible before, but further research work on a number of points in connexion with the disease is still required. This work is still being carried forward at the Waite Institute.

5. Tobacco Diseases.

(1) *Blue Mould.*

Introduction.—In January, 1929, arrangements were made with the Australian Tobacco Investigations Committee whereby the investigation of the "blue mould" disease of tobacco was to be undertaken by the Division of Economic Botany of C.S.I.R. The research committee, consisting of the Director of Tobacco Investigations and the Chief of the Division of Economic Botany, later assigned the problem to Dr. H. R. Angell, Senior Pathologist of the Division.

With a view to becoming acquainted with the disease in the field, visits were paid to the tobacco-growing districts around Myrtleford, Victoria; Tamworth, N.S.W.; Mareeba and Herberton, Queensland; and the Experiment Station at Wahgunyah, Victoria. During these visits, seed was collected from many farmers who had had blue mould during the previous season. Material from naturally-infected plants was also preserved for preliminary study of the relation of the parasite to the host.

Systemic Infection.—Blue mould is one of the principal factors limiting the expansion of the tobacco-growing industry in Australia. This disease does not occur in North America, in Europe, nor in most tobacco-growing countries. It is perhaps most destructive and of greatest economic importance when the plants are in the seedling stage. Under certain weather conditions favorable to the rapid development and spread of the causal organism, beds of seedlings may be entirely destroyed in a few days. Sometimes apparently healthy plants from the beds lightly attacked may be transplanted in the field, but more often than not they develop the disease and die within a week or two. This loss of seedlings and transplants necessitates the growing of successive seed-beds and several replantings—a series of operations expensive of time, patience, effort, and money. Should weather and other conditions be such that young tobacco plants infected with blue mould are able to survive the initial attack of the parasite, they may for a time fail to show any of the usual leaf symptoms of the disease, and indeed may appear to develop almost normally. Should, however, cross-sections be made of the older parts of the stems and petioles of such "recovered" plants there will be seen a brownish discoloration involving the parenchyma on both sides of the vascular ring. The amount of discoloured tissue decreases towards the upper portions of the stem. In both naturally and artificially-infected plants, discoloration of the tissue has been observed even in the peduncles and pedicels. Plants which are badly attacked appear to drop their fruit rather readily. Given certain conditions of temperature and humidity, the fungus may grow more rapidly than before and produce numerous and extensive lesions in the leaves. On such lesions, conidiophores and conidia are produced in abundance. Following these observations made with the naked eye, portions of tissue from the roots to the pedicels of naturally and artificially infected plants were fixed, dehydrated, embedded, stained and examined under the microscope. The intercellular mycelium of the fungus was found in sections of the root, stem, petiole, and lamina of the leaf as well as the peduncle and pedicel of the inflorescence. It has not yet been found in the fruit and seed.

Seed a Probable Source of Primary Infection.—The nature of the blue mould disease of tobacco very soon indicated the impracticability of control by spraying or dusting. Attempts by other workers have yielded indefinite results. Our investigations were therefore directed towards the discovery of the origin of primary infection. How did the first diseased plant in a seed-bed contract blue mould? Did the fungus live from one season to another in the soil, or in diseased over-wintering plants, or in wild hosts and produce crops of spores that infected the seedlings in the spring? Each of these factors appeared to be responsible to some degree for the perpetuation of the parasite, and indeed they may be very important on farms on which seedlings are grown in the same fields as mature plants. On visiting some of the tobacco-growing districts, however, it was learnt that some farmers grew their seedlings on new land in some cases hundreds of miles away from tobacco fields, wild tobacco, or other plants that may have had the disease. This information indicated that the source of infection was to be sought in another direction. It seemed fairly obvious that in such cases where seed was the only material transferred from the diseased tobacco fields to the distant seed-beds the disease was likely to be seed-borne.

Collections of seed from various Australian and North American sources was a time-consuming process, and it was some two months before Dr. Angell was able to secure a sample of seed from a lot that was definitely known to have produced blue mould plants first during the previous season. In two successive series of experiments conducted in a glasshouse in which samples of the North American and Australian seed were sown in flats laid side by side, the seedlings from the latter on both occasions developed the disease seventeen days after sowing, whereas the North American seedlings were perfectly healthy and remained so until they were deliberately exposed to infection from the others. A detailed account of this work is to appear in the August (1929) issue of the *Journal of Council for Scientific and Industrial Research*. One flat of treated Australian seed produced healthy seedlings, but the treatment given was not practicable for commercial application. It is to be regretted that as only a very limited amount of seed was available, no more experiments in seed treatment could be tried. Although these and other experiments leave little, if any, room for doubt that the disease is seed-borne and may prove to be amenable to control by seed treatment, the work must necessarily be repeated several times before making any definite recommendations. In the meantime, the results obtained should be taken as indicative. Other sources of infection are also being investigated.

Farmers are therefore advised that in order to prevent outbreaks of blue mould in their seed-beds—prevention is certainly better than cure in this case—they should be extremely careful in choosing their source of supply of seed. Only that obtained from healthy plants from disease-free fields in farms in which no blue mould was present during the past season, and preferably from districts in which blue mould does not occur, should be used for sowing. Until more is known regarding the disease, they are further advised to make their seed-beds on new land or at least on soil on which tobacco was not grown during the past season. Furthermore, the example of the farmers in the Myrtleford district, Victoria, should be followed if possible. Their seed-beds are removed by many miles from their fields and from possible wild hosts. Before transplanting in the fields, all tobacco plants in the neighbourhood which have survived the winter should be eradicated. In addition, farmers should seriously consider the advisability of selecting healthy seedlings of good type from disease-free seed-beds and transplanting them in an isolated field especially for the purpose of production of healthy seed.

(2) *Basal Stem Rot.*

Among the many diseases that have been observed during the season, a basal stem rot in the Tobacco Investigations Committee's experimental plot at Mareeba, Queensland, appears to be one that may be serious in wet seasons. Two organisms—Phoma and Colletotrichum—appeared to be generally associated with the trouble. Pure cultures of these organisms have been isolated and their pathogenicity will be tested as soon as field or greenhouse space and suitable temperature conditions are available.

(3) *Virus Diseases.*

Two well-known virus diseases, mosaic and ring spot, appear to be increasing in economic importance in the Myrtleford district of Victoria. In view of the great amount of loss caused by mosaic in the United States, it appears that growers would be well advised to take measures aiming at its control. Another disease, apparently hitherto undescribed and provisionally referred to as " bunchy-top " of tobacco, also appears to be due to a virus. Dwarfing of plants is quite common in certain fields. Its cause will be investigated as soon as time and opportunity permit.

6. Pineapple Diseases.

(1) *Water Blister of Pineapple.*—At the request of the Government of Queensland, Dr. Dickson was asked to look into a problem known generally as " water blister " of pineapples which had caused heavy losses. It is a trouble occurring in summer months, and not until January, 1929, were diseased pineapples available. It was then recognized as being the Thielaviopsis soft rot, fruit rot or black rot of pineapples, caused by *Thielaviopsis paradoxa*. The organism has been isolated in pure culture some fifty times, and inoculation studies abundantly confirmed the diagnosis. A questionnaire sent to pineapple dealers in Sydney and Melbourne brought to light the fact that the disease had been known up to 25 years, the average among the wholesalers being 15 years. Estimates of annual loss varied from 4 per cent. to 20 per cent., although in some individual consignments up to 90 per cent. loss occurred. The estimate of loss made by the Queensland Committee of Direction of Fruit Marketing is £7,500 per annum.

Mr. W. V. Ludbrook made twenty visits to Sydney markets and personally examined 1,148 rejected fruit of which 1,093, or 95.2 per cent. were soft-rotted, 42 or 3.7 per cent. were yeasty, 4 or 0.3 per cent. were both soft-rotted and yeasty, while 9 or 0.8 per cent. were bruised but not actually then diseased. Of the infections examined, 75.5 per cent. originated at or near the base of the fruit, 22.3 per cent. on the side, and 2.2 per cent. near the crown. Within 24 hours (under warm conditions) to several days after inoculation, a soft area develops which easily yields on slight pressure and from which juice oozes. This rapidly extends, and the internal tissues break down, releasing quantities of juice which runs or drips from the fruit, hence the market name of "water blister." The whole fruit may be involved in four to seven days, when it is reduced to a wet soft mass which is completely disintegrated and invaded by secondary bacteria and yeasts. The broken-down tissues carry the mycelium of the fungus and its spores, and by reason of the presence of the spores the pulp may be olive-green in colour. Upon exposure to air, a rapid development of hyaline microconidia occurs, giving the surface a glistening frosty appearance, followed by a darkening due to the development of masses of dark olive-green macroconidia.

The development of *Thielaviopsis* is checked by both low and high temperatures. Experiments showed that it would not grow in pineapple fruit at 37.5° C., nor at 10 to 12°C., but that it grows readily at 23–29° C.

By arrangement with the Committee of Direction of Fruit Marketing, consignments of fruit experimentally treated were shipped to us from Queensland. They were treated and packed by Mr. J. H. Simmonds, Plant Pathologist of the Department of Agriculture. Spore germination tests had shown that no growth occurred after treatment with ½ per cent. formalin for three minutes. Consignments of fruit treated with formalin were received from Queensland. These were free from water blister, but unfortunately the fruit surface was severely bronzed. On examination it was found that a discoloration and necrosis of tissues occurred to a depth of half an inch below the surface. Experimental tests showed that ½ per cent. formalin bronzed the greenish unripe tissues, but had little effect on the maturer yellow areas.

Other disinfectants such as sulphur, Bordeaux mixture, and Bordeaux plus formalin were tried at the same time without successful results. Care in cutting, handling, and packing of the pines definitely showed that by such means the losses could be materially reduced. Spore germination tests were then made with boracic and salicylic acids. With the boracic 1 in 400 prevented germination and with salicylic 1 in 7,200. Tests on fruit indicated that no discoloration occurs as a result of using these disinfectants. The shortness of the season available this year for experimental consignments—end of February to mid-April—allowed but little opportunity to test these disinfectants adequately on a commercial scale. It is planned to continue the consignments next season in the hope of finalizing control measures.

In the meantime, it is reiterated that care in cutting, handling, and packing will materially reduce losses. It has been stated in Hawaii that the organism can enter uninjured tissues. We have not demonstrated this, but it can certainly enter bruised tissues however small the bruise may be. Finally the organism is a soil-inhabitor. Pines dropped upon infested soil are probably inoculated by that method of handling, as is evidenced by the number of cases of basal rot occurring.

A technical account of the organism and the disease is in course of preparation.

(2) *Yeasty Pineapples.*—Out of the 1,148 pineapples examined by Mr. Ludbrook, 42 were found to differ in that no *Thielaviopsis* was present. They leaked juice as did the soft-rotted pineapples, but differed in other respects. On an affected area, a scum of yeast with bacteria may form and groups of frothy bubbles appear. On pressure the surface tissues sink and gas is evolved in large bubbles, or actually in quantity with a hissing sound. When the pressure is released the surface tissues return to their normal contour. When completely affected, all the juice disappears, chiefly as a result of fermentation, and only the skin and vascular tissues remain. A pineapple weighing three pounds is thus reduced to a weight of a few ounces. The fermentation gives rise to a definite acetic odour, and the acidity of the tissues effectually prevents other infection. Thus, if it happens that both fermentative and soft-rot organisms occur in the same pineapple they are sharply delimited one from another, for the *Thielaviopsis* will not grow into the fermenting area or zone.

Isolations to the number of 40 gave yeast cultures with, in a few cases, accompanying bacteria. Sixteen attempts to reproduce the disease were successful in only three cases, but further efforts may give more uniform results. Owing to the relatively minor importance of this trouble less attention has been paid to it than to the *Thielaviopsis* soft-rot.

7. Plant Disease Survey.

Plant diseases do not conform in their geographic distribution to political boundaries. Some are cosmopolitan and others local, or local for a time, and later becoming widespread. When one considers the number of men available for looking after human ailments, or of veterinarians for animal diseases, it is readily understandable that a tremendous task faces the few pathologists who are investigating the diseases of all the crops grown in Australia. It behoves scientists concerned with plant health to have available a maximum of information on the occurrence, conditions, severity and control measures of plant diseases not only in a State but in the Commonwealth and outside the Commonwealth.

At a meeting of plant pathologists held in Melbourne in September, 1927, it was resolved :—

1. That Plant Pathologists of the different States be instructed as to the occurrence of any new or serious disease that may be diagnosed in their respective States.

2. That it is desirable to exchange between the pathological branches in the different States the monthly, quarterly, or other reports on plant diseases prepared for the International Institute of Agriculture at Rome. .

3. That the Plant Pathologists of all the States agree to prepare for publication, as soon as possible, a plant disease census indicating the occurrence, distribution, and severity of plant diseases in their respective States.

It is the aim of the Plant Disease Survey of the Division of Economic Botany to organize this information on a Commonwealth basis and to maintain records available to all workers. It is hoped that State officers will collaborate in the organization and maintenance of the Survey as is the case elsewhere.

A commencement has been made by Mr. C. C. Brittlebank, who is working up the records from Victoria made available by the courtesy of Dr. S. S. Cameron, Director of the Victorian Department of Agriculture.

8. Mycological Investigations in Prickly Pear Control.

During July, 1928, at the request of the Commonwealth Prickly Pear Board, I visited the prickly pear area in order to look into the question of the possibility of fungi and/or bacteria playing a part in control measures. By the kindness of Mr. F. D. Power, of the Prickly Pear Lands Commission of Queensland, and Mr. Alan P. Dodd, Officer in Charge of prickly pear work for the Board, I was able to see a considerable area in the Chinchilla district. The work of the Board and its officers is the outstanding example of what is possible by concentrated long-continued scientific effort in the attempt at control of a widespread introduced pest. The direct and indirect results of prickly pear invasion by the caterpillar *Cactoblastis cactorum* are astonishingly interesting, and the effectiveness of the attack leads one to build strong hopes of ultimate control provided no unforeseen setback occurs.

Mycologically, however, it was found that following the attack of *C. cactorum*, a soft rot set in which sometimes spread to other parts than the cladode (segment) originally invaded. In all probability, it was a bacterial rot spread by the caterpillars, but technical laboratory study is needed to determine just what causes the rot. A *Gloeosporium* spot was commonly found in the area, and " sun-scald " was abundant in one district. Wherever the prickly pear was down as a result of *C. cactorum* attack it was literally black with fungal bodies, many probably those of saprophytes, which, however, were evidently completing the work of destruction.

The Board recalled its officer from North America and a programme of mycological investigations has been arranged. That officer (Mr. H. K. Lewcock, M.Sc.) brought with him some 250 cultures of organisms isolated from diseased prickly pear in various parts of North America and in Bermuda.

The Division has arranged to maintain these in pure culture. Should any be considered of possible use in prickly pear control, the necessary tests for pathogenicity on economic plants will be carried out by the Division on behalf of the Board.

9. Pure Cultures.

It is frequently necessary to study pathogenic organisms at times when the disease is not present and to be able to produce the disease under controlled conditions. It is also necessary to determine whether or not physiological specialization occurs in any given case, especially when preparing to breed for disease resistance, as is the case with stem rust of wheat. Finally, it may be necessary to compare an organism occurring in Australia with one from abroad. All of these requirements necessitate the maintenance of as complete a collection as possible of the fungi and bacteria causing disease in plants in Australia. The Division has already some 300 organisms in culture as a basis for this work.

10. Plant Breeding.

A commencement has been made on the accumulation of a collection of material for studying the genetics of inheritance of morphological and physiological characters of cereals. Most attention will be devoted to wheats as to yield, disease resistance, drought tolerance, &c. Investigations concerning yield factors have already been initiated.

Arrangements have been made to carry on the maize improvement work at Gatton College, Queensland, under the direction of Mr. McMillan, Senior Plant Geneticist. It is planned that studies on disease resistance with this crop will begin in the near future. Plans are under consideration concerning investigations into experimental plot technique under Australian conditions.

11. Noxious Weeds.

(1) *Noogoora Burr* (*Xanthium* sp.).—A serious menace to wool production in parts of Queensland is the spread of the clotburs or cockleburs generally known as Noogoora and Bathurst burrs. Loss occurs not only by depreciation of land but by the cost of removal of burr from wool. Noogoora burr apparently occurred first near Brisbane, at the Noogoora Station, whence it has spread alarmingly. It is quite cosmopolitan and probably originated in Asia Minor. Technically it is a Xanthium, and has been botanically known as *Xanthium strumarium*. There is some doubt as to its actual classification, and we find that Dr. Widder considers it to be *X. pungens*. Specimens have been sent to the Royal Botanic Gardens at Kew, and to Washington, for identification and comparison. The group is peculiar in that each burr possesses two seeds, one of which may germinate in spring, and the other in the following spring, or during the next suitable rainfall period. This aggravates the difficulty of control. They may produce but two burrs on small plants, or many on large plants, and a count on a bush plant 2 feet 6 inches high made by Dr. Dickson gave 1,437 burrs.

As no officer of the Division was available for a survey of the problem, Dr. Jean White-Haney was seconded from C.S.I.R. Headquarters for six months, as from 1st March, to investigate the weed in the field. A map is being prepared jointly with the Queensland Lands Department to show the present geographic distribution of the burr. A questionnaire has been sent out to pastoralists in order to ascertain facts regarding the first occurrence of burr, its spread, relation to weather, water-courses, stock routes, &c., whether stock eat it, and whether any insect or fungal enemies have been observed on it.

Peak Downs, Springsure, Longreach, Muttaburra, Hughenden, Richmond, Nelia, Julia Creek, Cloncurry, and Charters Towers have been visited. The infestation of burr occurs mainly in the watercourses, rivers, creeks, and bore drains, but in parts of some localities in which the rainfall is not particularly low, burr plants are thriving and fruiting at long distances from water. The most densely-infested districts noted so far are :—

Emerald to Clermont.

Flinders River, the river passing through the Richmond, Nelia and Julia Creek districts.

Muttaburra districts.

In these districts, during the months from December to April, as a rule, a fresh crop germinates with each heavy fall of rain. Those plants which germinate early usually grow to heights from 3 to 9 feet before flowering, and are easily seen, and so relatively easily destroyed. The plants from seedlings which develop late in the season are usually much abbreviated, and mature seed when from 1 to 8 or 9 inches high. If growing among grass, it is almost impossible to find these miniature plants, and it is these which form the most difficult phase of the problem.

Methods of Destruction Used by Graziers.—

1. *Hand Pulling.*—Wholly successful if thoroughly done, but it is almost impossible to obtain labourers who do the work thoroughly.

2. *Cutting below the surface of the soil.*—Not so satisfactory, as if any plants are cut off just above the surface of the soil, as is usually the case with some, burr-producing sprouts grow from the axils of the cotyledons, which are usually $\frac{1}{4}$ to $\frac{1}{2}$ inch above the ground.

3. *Burning off with grass.*—Burr plants are difficult to burn, and require a very large proportion of dry grass, &c., to cause them to be destroyed. It is doubtful whether the burrs, unless burnt to a cinder, are sufficiently injured by the heat to destroy the contained seed. Such burrs have been collected and are to be subjected to germination tests.

4. *Poisoning.*—Crowded plants are sprayed by means of hoses connected with specially-constructed sprayers, or by means of hand atomisers, according to the amount and density of the infestation. Ninety-five per cent. of poison used is arsenic pentoxide solution (1 lb. to 1 gallon of water, or two-thirds of 1 lb. to 1 gallon of water). In each case seen or heard of, 100 per cent. destruction has been recorded.

Complete destruction was also caused in the case of the only station in which arsenite of soda was the liquid sprayed, but on another station the majority of the plants which had been sprayed with S.O.S. eradicator, though dry and dead-looking, were putting out fresh green sprouts from the nodes. Samples of burrs from arsenic-killed plants have been collected for germination tests.

Natural Methods of Destruction.—Plants completely submerged by overflow water for a few days are usually completely killed. Plants which have sprung up away from watercourses, in soil made boggy by rain, will usually die before the burrs reach maturity if later falls of rain do not occur.

Mice and white ants are reputed to eat the seeds in times of stress. Cockatoos eat the seed from the burrs, but it is almost universally reported that in this case many of the birds die quickly, being picked up round about the area infested with burr. The investigation is being continued.

(ii) *Control of Bracken.*—Bracken (*Pteridium aquilinum*) is cosmopolitan in distribution and is a pest wherever it occurs. To eradicate it by cutting requires from three to seven years, and consequently cost is an almost prohibitive factor on large areas. Any means of natural control is therefore worth investigating. During the last two or three years, a curious dying back of bracken has been noticed in Ayrshire, Scotland, particularly near Maybole. In the summer of 1928, the same condition was observed on the slopes of the Logan Valley, and during the summer it was reported from many separated areas distributed practically over the south of Scotland. Fronds looked as though touched by frost, but young protected fronds developed black blotches containing fungal growth. The evidence so far is circumstantial, but it looks as though a fungus is affecting the bracken and gradually killing it out.

Dr. E. J. Butler, Director of the Imperial Bureau of Mycology, was communicated with, and he arranged with Mrs. N. J. Alcock, Pathologist of the Department of Agriculture for Scotland, that cultures should be made available to the Division of Economic Botany. Such have been received and are being studied under controlled conditions in the hope that they may be of value where bracken is a pest, as in Tasmania and New Zealand. The organism suspected as the cause of the disease is *Rhopographus pteridis*.

12. The Koonamore Vegetation Reserve.

Large areas of the inland parts of Australia are arid, having an average annual rainfall of 10 inches or less. The natural vegetation in the more favoured parts is an open scrub woodland with undergrowth of half-shrubby Chenopodiaceous perennials, chiefly species of *Atriplex* and *Kochia*. In less favoured portions the latter are the dominants over great areas. These areas are exploited for pastoral purposes, largely merino wool, whenever sufficient water can be conserved by dams, wells or bores (artesian and sub-artesian). The fodder plants are a mixture of grasses and herbage which appear following suitable rains. At other times the perennial Chenopods provide the bulk of the browse.

The influence of stocking on the perennials is seen in a pruning effect, in reduced seed production, and in damage through trampling. This last in severe cases leads to complete destruction of the low-growing perennial vegetation and inhibition of reproduction of trees and shrubs. Problems of erosion and drift result in varying degrees of severity, culminating in a condition of artificial desert. The influence of rabbits in preventing regeneration is very severe.

For several years, Professor T. G. B. Osborn, then of the University of Adelaide, had worked on the ecology of arid areas in South Australia. In 1926, the proprietors of Koonamore Station gave to the University of Adelaide an area of about 1,200 acres of eaten-out country for experimental purposes, enclosed it with a rabbit-proof fence, and built a small field laboratory adjacent. In 1928, when Professor Osborn was appointed to Sydney, the University of Adelaide asked him to continue the oversight of the experiments for a time. The Council for Scientific and Industrial Research made a grant for capital improvements and an annual appropriation for running costs as well as the salary of a resident field officer.

The programme of experiments at Koonamore was primarily planned to study the natural regeneration of the vegetation under total protection by means of quarterly observations on quadrats of various sizes. Since the co-operation of C.S.I.R., it has been extended to include observations on stocking effect around watering places on the surrounding pastorally occupied country. The work has obvious relations to agrostology and plant introduction. The size of pastoral holdings in arid areas is such as to preclude any direct methods of improvement other than by casual seeding, but the importance of indirect improvement by conservation of seed areas is being studied.

The facilities at Koonamore consist of a three-roomed field laboratory adjacent to the reservation. A resident field officer (Mr. T. B. Paltridge, B.Sc.) is stationed there. He works under the direction of Professor Osborn, who makes periodic visits assisted from time to time by members of the Adelaide University Botany Department. Koonamore is located 40 miles north of Yunta, on the Broken Hill-Peterborough Railway, at an altitude of about 1,500 feet within the 8-in. isohyet.

The investigation is obviously a long-dated one. At present, three years' records from the quadrats are available. A body of data is accumulating on the effect of total protection checked by the effect of commercial grazing in the surrounding area. Experiments on artificial regeneration of mulga (*Acacia aneura*) after fire, have given promising results. Line transects have been run from numerous wells in the surrounding district for distances up to three miles from the water, and observations made on the number and state of the perennial fodder plants. It is expected that results from these will be ready for publication within the next year.

Experiments in the experimental sowing of native and introduced fodder plants are being made, but this and other work has been hampered by drought conditions, which have prevailed during the past three years throughout the north-east of South Australia.

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COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

THE WORK OF THE

DIVISION OF ECONOMIC ENTOMOLOGY

FOR THE YEAR 1928-29

By

Dr. R. J. TILLYARD, M.A., Sc.D., D.Sc., F.R.S.
Chief of the Division

MELBOURNE, 1929

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Council for Scientific and Industrial Research

THE WORK OF THE

DIVISION OF ECONOMIC ENTOMOLOGY

FOR THE YEAR 1928-29

By

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Chief of the Division

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Work of the Division of Economic Entomology for the year 1928-29.*

By R. J. Tillyard, M.A., Sc.D., D.Sc., F.R.S., Chief of the Division.

I. CREATION OF THE DIVISION—PERSONNEL.

The creation of a Division may be said to date from two events; firstly, the acceptance by the Executive of a definite scheme or plan of research for the Division, and secondly, the appointment of a Chief to carry it into effect. Creation, however, is not a single act, but a long evolutionary effort, and so it may be said that the creation of a Division still continues as long as the research staff provided for in the original plan remains incomplete.

From this point of view, the creation of the Division of Economic Entomology began in October, 1927, with the adoption of the scheme suggested by Dr. Tillyard, and was advanced a step farther with the appointment of the latter as Chief of the Division as from 1st March, 1928, while Mr. G. F. Hill, already on the Council's staff, became Assistant Chief and Senior Entomologist for Field Pests Research.

The original scheme supplied by Dr. Tillyard was published in an abbreviated form in the *Journal of the Council for Scientific and Industrial Research*, Vol. I., No. 4, May, 1928. In a foreword to this Report, the Editor of the Journal made the following remark:—

> "It will not be possible for the Council to give immediate effect to all Dr. Tillyard's recommendations, as the present shortage of trained entomologists, apart altogether from financial considerations, constitutes a serious difficulty."

The difficulty mentioned in this passage has proved to be fully as real as was expected. Three senior positions were advertised in *Nature* and the leading papers of Australia and New Zealand early in 1928, and most of the applicants were interviewed by Dr. Tillyard while in England and America. A high standard of ability and experience was essential in those selected to occupy such posts. None of the applicants reaching that standard, no appointments were made. Australia and New Zealand, however, have since supplied men of the standard required, though, at the present time, one senior position is still vacant, no suitable man having so far been found. Three seniors and one entomologist-in-charge have been secured from Australia and one senior from New Zealand.

The progress of the Division, as measured by the filling of posts recommended in the original scheme, may best be gauged by a statement of the classified *personnel* as at the end of the period covered by this Report (30th June, 1929):—

1. Noxious Weeds Research.

Mr. G. A. Currie was appointed Entomologist-in-charge of this Section in March, 1929. Mr. S. Garthside was appointed Junior

* Typescript received 26th July, 1929.

Entomologist as from July, 1928. There being no Senior Entomologist in this Section at present, the Chief Entomologist is personally directing the research.

2. Blowfly and Buffalo-fly Researches.

The original scheme envisaged separate Senior appointments for blowfly and buffalo-fly researches. The two lines of research are, however, closely allied, and a single Senior Entomologist, Dr. I. M. Mackerras, has been appointed to take charge of both of them from October, 1928. Dr. F. G. Holdaway was appointed Junior Entomologist in blowfly research as from July, 1928, and Miss M. Fuller, Assistant Entomologist in blowfly research from March, 1929.

In buffalo-fly research, Mr. T. G. Campbell, originally appointed as Assistant to the Curator in January, 1929, was seconded for work in Northern Australia as from 7th March, 1929, and Mr. G. L. Windred was appointed Assistant Entomologist to proceed to Java in April, 1929.

3. Orchard and Fruit Pests Research.

No senior Entomologist has yet been appointed for this section. The only officer at present is Mr. J. W. Evans, appointed Junior Entomologist in charge of codlin-moth research as from July, 1929.

4. Field-crop and Pasture Pests Research.

Mr. G. F. Hill, is Senior Entomologist in charge of this section. He took up his residence in Canberra at the end of January, 1929. Mr. H. J. Willings was appointed his Field Assistant in April, 1929.

5. Forest Insects Research.

This section has not yet been organized, but arrangements are well forward for starting it during the ensuing year.

6. Museum and Library.

Dr. G. A. Waterhouse was appointed Curator of the museum in October, 1928, and has also had charge of the library. Pending the completion of the new laboratory buildings at Black Mountain, temporary offices were secured at No. 12 Melbourne Buildings, Civic Centre, Canberra, where the upper story is divided into four rooms to serve as offices for the Chief, the Assistant Chief, the Entomologist in charge of Noxious Weeds and the typiste. The ground floor, shared with the Division of Economic Botany, is being used to house the collections and library, and is in charge of Mrs. Willings, appointed in April, 1929, as Entomological Assistant to the Curator.

During the period of his appointment, Dr. Waterhouse had his office in Sydney, firstly at the Zoological School, University of Sydney, and more recently at No. 10 Bull's Chambers, Martin Place. From February, 1929, he was also appointed Executive Officer for the Division. He resigned his position as Curator and Executive Officer in April, 1929, but very kindly agreed to continue his work pending the appointment of his successor.

Mr. A. L. Tonnoir has been appointed Senior Ecologist as from 1st September, 1929, and will have charge of the expert technical side of the researches, including the cool-store, constant-temperature chambers, artist's and photographic section, microscopes, and apparatus.

7. Typistes.

Mrs. Benham, appointed temporary Entomological Assistant in February, 1929, has been doing chiefly typing work in Dr. Waterhouse's office in Sydney. Miss G. Shaw, assistant typiste, was appointed in February also, and is working at Canberra.

Thus it will be seen that the entire staff consists at present of a Chief, an Assistant Chief, three other officers of senior standing (including the Curator and Senior Ecologist), one Entomologist-in-charge, three Junior Entomologists, four Assistant Entomologists, one Field Assistant and two Typistes—a total of sixteen, including the Ecologist. Of these, twelve are men and four women.

In addition to the above, two graduates are being trained in London for positions as Assistants in the museum, viz., Miss W. Kent Hughes (Coleopterist) and Miss L. Graham (Hymenopterist). These will join the staff at Canberra during the coming year.

II. GENERAL POLICY.

The general policy of the Division may be briefly stated as follows :—

(1) Except within the bounds of the Federal Capital Territory itself, where a certain amount of advisory work has to be done under the arrangement whereby the Chief of the Division is also Consulting Entomologist to the Federal Capital Commission, the work of the Division will be entirely research work.

(2) The lines of research to be undertaken are delimited broadly by the term "methods of biological control." These include two important subdivisions, as follows :—

(*a*) Control of noxious weeds by their natural insect enemies, and

(*b*) Control of insect pests by beneficial parasites or predators.

Other methods of control are not ruled out in laying down this general rule, especially where a difficult problem, like that of blowfly, calls for intensive research in all possible directions.

(3) The original scheme, having in view more particularly the marked shortage of trained entomologists, also stressed the necessity for training. While this ideal will not be lost sight of, it is evident that, in the initial stages of development, it will not be possible to do very much along the lines suggested.

(4) The policy of the Division is not to trench on the activities of the State organizations, but to work in co-operation with them where desirable. This ideal is steadily being put into practice. At the present time, the Division is co-operating with the Department of Agriculture

and Stock in Queensland on the buffalo-fly problem, and with the Department of Agriculture in New South Wales on certain aspects of the blowfly problem. The National Museum, Melbourne, and the Australian Museum, Sydney, have both given us valuable help in systematic work. Negotiations are also in progress with the Waite Institute, South Australia, with a view to close co-operation on the problem of lucerne flea, and with the Trustees of the South Australian and the Queensland Museums on the subject of co-operation in systematic entomology. Outside of Australia, a close connexion has been established with the Imperial Bureau of Entomology through the new Farnham House Laboratory at Farnham Royal, where three Junior Entomologists have been working during the past year, and with the Department of Entomology at the Imperial College of Science and Technology, London University, where two Assistant Entomologists have been undergoing a course of training. We also have a student carrying out a specific piece of noxious weeds research on our behalf at the Kansas State Agricultural College, Manhattan, Kansas, U.S.A., and have received valuable help from entomologists in Java on the problem of buffalo-fly.

(5) The work of the Division at Canberra brings us into close touch in many ways with the Federal Capital Commission. It is a pleasure to record the consistent interest, sympathy and help received from the Chief Commissioner, Sir John Butters, his fellow Commissioners, and the various branches of his staff during the course of the year's work. As Consulting Entomologist to the Commission, the Chief of this Division furnishes a separate report annually.

III. BUILDINGS.

1. General.

The Division of Economic Entomology has its centre at Canberra, where the main Laboratory buildings are now being built on the Council's new site at Black Mountain, at the end of University Avenue.

The buildings consist of :—

(1) The Administrative Block to be shared with the Division of Economic Botany.

(2) The Entomological Laboratory Block.

(3) The Quarantine Insectaries.

(4) The Blowfly Unit.

Of these, Nos. (1) and (4) are not yet begun.

2. The Laboratory Block.

This building was begun in February last. The architects are the Federal Capital Commission, the contractors Messrs. Simmie & Co. The contract price for the building is £17,990, and the estimated total cost, inclusive of all services, is approximately £22,000.

The building is of brick, with cement facing. The design is extremely simple, the aim being to give the finest laboratory service and conditions for the money available. The block of buildings is rectangular, 134 feet in length by 48 feet wide, and two stories high, with a flat roof suitable for experimental work when required. The building faces approximately south-east. Each floor is divided from end to end by a main passage six feet wide, on either side of which the laboratories are placed. These are designed in units of 5½ feet width, thus allowing of the partitioning of the available space into rooms either 11·0, 16·5, 22·0, 27·5 or 33·0 feet wide, as required Except for the rooms at the south end, which are of fixed size and specially designed as a cool-store on the ground floor and dark-rooms above, all the partitions are removable and built of terra-cotta bricks. Thus the design lends itself to ease of alteration if further blocks are built later on. The windows are high and open at the top, in a manner to obviate draughts for men working at the benches. The window-reveal, externally, is carried up through the two stories, thus greatly increasing the effectiveness of the design architecturally.

Below the ground level, at the north end, is placed a large boiler-house in which are the main boilers for the heating service throughout the building, the fuel used being crude oil. At the south end, below the cool-store, is another large chamber divided into two unequal portions; these are to be fitted up as controlled-temperature chambers. Extending from these beneath the main passage for some distance is a narrower chamber to contain the fans which control the air circulation. These underground chambers are reached by a stairway beneath, and parallel to, the stairway leading from the ground-floor to the top story.

Gas-supply is of the greatest importance in a scientific laboratory. As the city of Canberra has no coal-gas supply, the new building is to be fitted with a complete petrol-gas supply of its own. Electric light and power is also supplied to every room, and there is an efficient water and sewerage service. Lavatory accommodation is provided for both floors.

On the ground floor, facing south-east there will be, for the present, seven rooms, viz., the laboratories for the Chief Entomologist, Deputy Chief, and four Senior Entomologists, together with a room for the typistes. Across the main passage, facing north-west, there will be five rooms, exclusive of the cool-store, viz., a large room to be used as temporary museum and library, and four laboratories for Junior Entomologists and Assistants; one of the smaller rooms will be used as a temporary store-room.

The rooms on the top floor will be occupied temporarily by the Division of Economic Botany, pending the completion of their own laboratory block near by. The Entomological Building is intended to form the southern wing only of a more complete structure, in which the similar northern wing will form the Botanical Laboratory Building, while the central Administrative Block will connect the two wings and will house the permanent museum, library, offices of the Chiefs and Deputy Chiefs of the Divisions and of the clerical staff.

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3. The Quarantine Insectaries.

Behind the Entomological Laboratory Building, an area has been levelled sufficient to allow for the erection of four large insectaries of modern type. For the present year, only two will be put into commission. These have just been completed. Each insectary is a complete quarantine unit, consisting of baffle-chamber, quarantine store-room, and enclosed large insect chamber or insectary proper. The design of each insectary follows fairly closely the original design of the insectary of the new Biological Laboratory of the Cawthron Institute, Nelson, N.Z., especially in the raised roof, giving good ventilation to the quarantine chamber below. The latter is closed in partly with fine phosphor-bronze gauze, 60 meshes to the inch, protected outside at a distance of 4 inches by strong wire-netting of ¼-in. mesh, and partly by panels of reinforced glass. The number and arrangement of the glass panels in roof and sides is different in the two insectaries, in order to test the lighting effects over the various seasons of the year. The problem of designing a large quarantine insectary which shall give suitable lighting for the natural growth of plants and insects, without undue heating or increase of humidity, and at the same time fulfil quarantine requirements in preventing the ingress or egress of even the smallest insect, is one that is not easy of solution ; but it is hoped that this new design comes close to fulfilling all requirements.

Two roof-lights and two power-points are provided in the quarantine insectary, together with an extra power-point above the roofing gauze, for cleaning purposes. Each insectary, measuring approximately 40 feet square, is divided up into sixteen smaller divisions, each of which has its own special tap for water-supply. By means of wooden frames, each of the four small divisions on north and south sides can be closed off into a single unit, while the middle portions can be separated up into two larger divisions.

The baffle-chamber is a dark chamber provided with one roof-light which gives access both to the insectary proper and to the store-room. The object of this chamber is to prevent insects being carried in or out of the quarantine area on the clothes of the workers. An ingenious mechanism gives interlocking conditions between the door leading into the baffle-chamber and that leading from it into the insectary proper, so that, as soon as one door is opened, the other is automatically locked. The latter door also has, on its insectary side, a wooden cage enclosed with gauze, the entry into which is by means of a large glass funnel pointing inwards from the baffle-chamber. As the latter is painted dark green inside, any insect that accidentally finds itself in the baffle-chamber will return to the light through the funnel into this cage.

The store-room is fitted with a small bench and shelves, and its door is provided with locks and bolts. The window is of fine gauze protected externally with wire-netting as in the insectary proper. The store-room and insectary are painted creamy white inside.

No. 1 Insectary (to the south) will be devoted to noxious weeds researches, principally St. John's wort, and will be under the charge of Mr. G. A. Currie.

No. 2 Insectary (to the north) will be principally used for experiments on the control of grass-grubs, and will be under the charge of Mr. G. F. Hill.

These two insectaries are in process of being planted with St. John's wort and various grasses respectively.

4. Temporary Blowfly Unit.

Pending the designing and erection of the permanent blowfly unit, at Black Mountain, behind the insectary site, a temporary blowfly unit, consisting of a small quarantine insectary and a workman's cubicle fitted up as a small laboratory, has been erected at Red Hill, at the back of Dr. Tillyard's property. These are under the charge of Miss M. Fuller, and are being used for the rearing of *Alysia manducator* and for other experiments on blowflies. The experience gained in these quarters will prove of considerable value in improving the design of the permanent blowfly unit.

IV. INVESTIGATIONS IN PROGRESS.

1. Noxious Weeds Research.

The work on noxious weeds research is being undertaken by the Chief Entomologist, Dr. R. J. Tillyard, and Mr. G. A. Currie, Entomologist-in-charge, at Canberra, while Mr. S. Garthside is also at work on the same problem at Farnham Royal, and Mr. S. Kelly at Manhattan, Kansas.

The work at Canberra is centred in Quarantine Insectary No 1, which has just been completed and put into commission, and is now in process of being planted out with St. John's wort (*Hypericum perforatum*), ragwort (*Senecio jacobaea*) and Bathurst and Noogoora burrs (*Xanthium* spp.). The plots of these weeds should be in good condition by the coming spring, when the first consignments of insects from abroad may be expected.

(*a*) *St. John's Wort* (*Hypericum perforatum*).—To date, work in Australia has been of a preliminary or investigatory nature only. Previous to his appointment, Dr. Tillyard had visited the Ovens Valley in Victoria and convinced himself of the seriousness of the St. John's wort infestation in that district. Since that time, a more general survey of the infested areas has been made, and a preliminary report has been drawn up which will later on be attached as an introduction to the first entomological report on the control of this weed. In April, Dr. Tillyard visited the extensive area of infestation in Gippsland, and also studied the infestation by an allied weed, tutsan (*Hypericum androsaemum*), around Apollo Bay, Victoria. In May, Dr. Tillyard and Mr. Currie studied the infestation at Mannus, near Tumbarumba, New South Wales, and in June, Mr. Currie visited Mudgee, New South Wales, where there is another fairly extensive infestation of the same weed. Dr. Tillyard also collected information concerning the spread of this weed in South Australia during his recent visit to Adelaide. These investigations have yielded valuable results concerning the type of country infested, the absence of control by insects or fungi, the inability of the weed to grow without a good rainfall, the marked changes in the habit of growth as compared with its habit in England, the ability of the weed to overcome all other native and introduced vegetation except bushes and trees, its methods of propagation and spread, and its effect on various kinds of animals. The most compact and complete infestation noted anywhere in Australia is that at Mannus, near Tumbarumba, which therefore offers the most ideal conditions as a centre for experiments in biological control by insect enemies.

At Farnham Royal, Mr. Garthside has been studying the life-histories of various groups of insects known to be confined to the genus *Hypericum* as food-plant. The chief of these are a group of closely allied species of beetles of the genus *Chrysomela*, a group of gall-midges (*Cecidomyiidae*), a Buprestid beetle (*Agrilus hyperici*) which bores into the stem, two species of Geometroid moths of the genus *Anaitis*, and a Tortricid moth, *Lathronympha hypericana*, whose larvae attack the young shoots. All these appear promising. The greatest progress has so far been made with the study of the species of *Chrysomela*. In the case of *Chrysomela hyperici*, tests made with (*a*) young larvae, (*b*) fourth instar larvae, and (*c*) adult beetles, on 40 different varieties of economic plants have so far yielded entirely negative results. During the present European summer, Mr. Garthside intends to conduct as many tests as possible on the above insects, and also to collect supplies preparatory to shipment to Australia. The first shipments should be those of the genus *Chrysomela*, which it is hoped will be available for testing at Canberra by the coming Australian spring.

The present position regarding this weed may be regarded as highly promising and may be summarized as follows :—

(1) Although, at the present time, St. John's wort covers an immense area (estimated at from 250,000 to 400,000 acres in Victoria, and has also closely-infested smaller areas in New South Wales and South Australia), there is not a single insect* or fungus attacking it anywhere; in other words, it is not controlled at all by natural enemies.

(2) Investigations in Europe show that the plant is attacked at many stages (stem, shoot, growing-tip, leaves and buds), by a considerable fauna of highly specialized insects, all of which, so far as at present known, are confined to the genus *Hypericum*.

(3) Though all these insects are in their turn checked to a large extent by their natural parasites, the amount of damage done to the weed is very considerable.

(4) Hence the amount of control likely to be attained by these same insects, introduced into Australia and liberated after elimination of all their parasites, is bound to be very great, and should, in time, lead to complete control of the weed in all heavily-infested areas.

* Except for an occasional individual of a species of Spittle-insect (Cercopidae).

It needs only to be added that the work of elimination of parasites and of thoroughly testing the insects in all stages, to make sure that they can feed only on *Hypericum*, will be carried out entirely in the Quarantine Insectaries at Canberra.

(*b*) *Bathurst and Noogoora Burrs* (*Xanthium* spp.).—Arrangements have been made with Professor G. Dean, Department of Entomology, State Agricultural College, Manhattan, Kansas, for research to be carried out on the native North American insects that attack species of the genus *Xanthium*. This work is being undertaken by Mr. Samuel Kelly during the present summer. Mr. Kelly will make special efforts to find an effective seed-destroyer, since these bad weeds are spread by means of the seed.

(*c*) *Ragwort* (*Senecio jacobaea*),—In view of the importance of controlling this weed in Victoria and Tasmania, arrangements are being made with the Cawthron Institute, Nelson, for a supply of pupae of the Cinnabar Moth, *Tyria jacobaea*, which was introduced into New Zealand by Dr. Tillyard in 1925 for the purpose of attempting to control this weed. An exhaustive series of tests since carried out in Nelson has shown that this insect causes very great destruction to ragwort and is harmless to all other economic plants. It is at present being liberated in ragwort-infested areas in New Zealand, and should certainly be tried out in Australia also.

(*d*) *Other Noxious Weeds.*—During a recent visit to Cowra, Bathurst and Mudgee, Mr. Currie carried out some preliminary work on skeleton weed (*Chondrilla juncea*) and saffron thistle (*Kentrophyllum lanatum*), both of which are serious weeds over large areas of Australia.

2. Sheep Blowfly Problem.

This work is under the charge of Dr. Ian Mackerras as Senior Entomologist of this Section. Owing to the more immediate importance of the buffalo-fly problem, and Dr. Mackerras's consequent absence in Java and Northern Australia, the work on the blowfly problem has for the present been confined to two separate lines of research, as follows :—

(*a*) *Introduction and acclimatization of the parasite Alysia manducator at Canberra.*—Pending the completion, later on, of a special blowfly unit behind the new laboratories at Black Mountain, this work has been carried on in the small temporary blowfly insectary and laboratory situated in the grounds of Dr. Tillyard's residence at Red Hill. Miss M. Fuller has charge of the work, under Dr. Tillyard's direction. Three consignments of *Alysia* have been introduced during the past year, two from New Zealand and one from the Department of Agriculture in Sydney. The first New Zealand consignment was accidentally destroyed in a storm. The Sydney consignment yielded but few individuals and died out in the second generation. The second New Zealand consignment proved to be heavily infested with the hyper-parasite *Mormoniella brevicornis*; but Miss Fuller succeeded in entirely eliminating this in the second generation, and has also succeeded in rearing a large third brood, a portion of which emerged during April and May, while many more parasitized puparia are being carried through the winter. It thus appears as if *Alysia* has been successfully acclimatized to Canberra conditions. In the coming spring, the experiment will be continued along the lines of establishing successful colonies of the parasite out in the open around the city of Canberra.

Other accessory lines of work carried out by Miss Fuller consist of studies of the succession of blowfly species attacking exposed carcasses and the changes in this succession through the different seasons of the year, a study of the conditions of control of blowflies at the abattoirs and elsewhere, and a study of the insects that feed in cow-manure. Dr. Tillyard, working in collaboration with Dr. Butler, Medical Officer of Health to the Federal Capital Commission, has worked out a scheme of blowfly control for the city area by means of a ring of specially constructed traps which will be baited and emptied twice a week during the summer months. This scheme has been adopted by the Commission.

The aim of the above work is to test how far, by the use of parasites, traps, or other methods, actual control of blowflies can be secured in the Federal Capital City area.

(*b*) *Work at Farnham Royal as Centre*.—Dr. Holdaway was appointed to the post of Junior Entomologist for blowfly research, and started this work at Farnham Royal in October, 1928. His work is at present along two distinct lines. In collaboration with workers at Leeds University, he is studying the factors which cause "blowing" in wool. He is also making a search of Southern Europe for new parasites of blowflies, and has taken up his quarters for the present European summer at the University of Toulouse, France.

During the winter, Dr. Holdaway carried out some useful systematic work on the Calliphoridae, and has more especially examined the systematics of *Chrysomyia rufifacies* Macquart and *Ch. albiceps* Wied., his conclusions being that both the larvae and adult flies afford good characters enabling them to be distinguished as valid species.

3. Buffalo-fly Problem.

This work is under the direct charge of Dr. Ian Mackerras as Senior Entomologist for blowfly and buffalo-fly researches. Assisting him are Mr. T. G. Campbell in Northern Australia and Mr. Windred in Java.

Reports received early in 1929 that buffalo-fly had crossed the border between Northern Australia and Queensland, led to the recognition of this problem as one of extreme urgency, and to a decision to co-operate with the State of Queensland in studying the problem. At the end of February Mr. T. G. Campbell was sent to Darwin to make a special study of the fly in Northern Australia, to work out details of its life-history, to try to discover how far it might breed in the dung of native animals, and to follow the herds of cattle travelling towards the Queensland border with a view to discovering how far any proclaimed buffer area might be effective in stopping the entry of the fly into Queensland. Two preliminary reports received from Mr. Campbell indicate that he has already collected together a great deal of valuable information about the fly, and also establish the important fact that the two more southern stock routes into Queensland are still free from the fly.

In April, Dr. Mackerras and a newly appointed Assistant Entomologist, Mr. G. L. Windred, left for Java, where they attended the Pan-Pacific Congress and began the study of the buffalo-fly in that region. While Mr. Windred is remaining in Java to carry on work in connexion with parasites of the fly, Dr. Mackerras has visited Timor and the intervening islands, and has collected much valuable information on the prevalence of buffalo-fly, house-fly and blowflies in the Dutch East Indies. He has been struck by the remarkable fact that, with a range of climate varying from intense tropical rainfall to dry conditions closely resembling those found in Australia, with both native and introduced cattle present, with a teeming population of mixed races and an abundant supply of domestic animals—conditions which one would naturally conclude were ideal for flies of all kinds—neither buffalo-fly nor blowflies, nor even the ubiquitous house-fly, is at all a pest. Factors must therefore operate to control all these pests, and the problem is to determine what these factors are and whether they can be applied in Australia. As the buffalo-fly has no parasites attacking it in Australia, but is known to be parasitized in Java, parasites must be one of the factors in control there; the problem is to decide whether it is the most important factor, and, if so, what type of parasite is the most effective.

While in Timor, Dr. Mackerras discovered there a new parasite of the genus *Musca* (house-fly) which he considers important. A supply of this is being sent to Australia for study under quarantine conditions.

Dr. Mackerras is due to arrive back in Darwin about the middle of July, 1929, and will be met there by Mr. Campbell. He intends to travel by the overland route to Wyndham, Western Australia, whence he will take boat for Fremantle. A conference will probably be arranged in August or September between Mr. Sutton, Director of Agriculture for Western Australia and Drs. Tillyard and Mackerras to discuss the position as it affects Western Australia. Mr. Windred is remaining in Java for the present, and Mr. Campbell still has a great deal of work to do in Northern Australia

4. Orchard and Fruit Pests.

This section is not yet fully organized, as it has not been possible so far to secure a suitable Senior Entomologist to take charge of it. The post is one of the most important in the whole Division, and the selection of a very highly-trained entomologist to fill it is essential. Efforts are at present being made to find a man of the type needed for this post.

(i) *Work at Farnham Royal.*—In the meantime, work in this section has been carried on at Farnham Royal, where Mr. J. W. Evans, Junior Entomologist in fruit pests research, has been carrying on his studies of the control of codlin moth by means of the parasite *Trichogramma minutum*. The principle here involved, as developed by Flanders in

California and by Jones in Massachusetts, is the same that gave successful control of mealy-bug by *Cryptolaemus* in California. Various species of *Trichogramma* are already of world-wide distribution as egg-parasites; but, in the case of codlin-moth, they do not attain to a high degree of control of their hosts, owing to their late emergence in the spring compared with their host's first brood. If, however, the parasites can be raised in large numbers on an alternative host in a warm insectary in the late winter or early spring, and then placed out in sufficient numbers in the orchards affected with codlin-moth, control of this pest might be obtained at a much lower cost than by using arsenical sprays. A further advantage that makes this method attractive is that it should eliminate the possibilities of a recurrence of the "arsenic scare," which has seriously damaged the prospects of the sales of Australian and New Zealand apples on the English market more than once.

Mr. Evans has made such good progress with his studies of the races of *Trichogramma*, the utilization of alternative hosts, and new methods of improving the technique of the problem, that he is now on his way back to Australia with a good supply of three distinct races of the parasite, which will be tested under Australian conditions during the coming year.

(ii) *Dried Fruit Pests.*—As the result of a visit to Merbein, when he conferred with Mr. A. V. Lyon, Mr. G. F. Hill has presented a report on the present position regarding the dried fruit grub (*Plodia interpunctella*) stressing the importance of enforcing the regulations already in force concerning this pest.

5. Field-Crop and Pasture Pests.

Mr. G. F. Hill, is Senior Entomologist in charge of this Section, but a Junior Entomologist has not yet been appointed. During the year, Mr. Hill's completed preliminary investigation of the problem of the Tasmanian grass-grub, *Oncopera intricata*, has been published as a Pamphlet of the Council. In it, the conclusion is reached that, except on highly-valuable land where expensive chemical treatment might be justified, the only hope of control lies in the discovery of a natural parasite.

The only known parasites of Hepialid larvae of the type of *Oncopera* in Europe are the Ichneumonids of the genus *Allomyia*, but very little is known about them. An investigation along these lines is needed, but the work is clearly very difficult and a well-trained and capable researcher is required for it. Quarantine Insectary No. 2 is at present being planted with plots of various English grasses with a view to rearing *Oncopera* larvae preparatory to testing out possible parasites.

The programme of research in this section includes also a study of the lucerne flea (*Sminthurus viridis*) which is an exceptionally bad pest in South Australia. It s hoped to make arrangements whereby a Junior Entomologist appointed by the Council may be enabled to work on this problem under Dr. Davidson, Entomologist to the Waite Institute, Adelaide.

During the summer, a study of the problems of control of ants was made by Dr Tillyard and Mr. Hill, the result being that a calcium cyanide fumigant, properly used, was found to be a highly effective control under the dry climatic conditions of Canberra.

6. Forestry Problems.

During the year just ended, no Forest Insects Section was formed. The Division, however, possesses the nucleus of such a Section in so far as Mr. G. F. Hill is a recognized authority on termites, and Mr. Garthside has been specially trained in forest entomology and is continuing his studies in that direction while working at noxious weeds research. It is hoped, during the coming year, to effect a re-arrangement whereby those officers who possess special knowledge of forest insects may be brought together to work on them. The huge annual losses suffered by Australia through white ants alone would justify the appointment of a full-time worker on this group.

V. SPECIAL SERVICES.

1. The Museum.

The collections which form the nucleus of the entomological museum are at present housed on the ground door of No. 12 Melbourne Buildings, Civic Centre, Canberra. They consist of the following distinct units :—

(1) *The Froggatt Collection.*—The collection of insects made by Mr. W. W. Froggatt, for many years Government Entomologist of New South Wales, was purchased by the Department of Home Affairs and handed over to the Council shortly after the formation of this Division. Prior to its transference to Canberra in January last, it was under the care of Mr. G. F. Hill in Melbourne. It consists of 61 store boxes containing specimens of all orders of insects, together with a number of jars of spirit specimens. Most of the specimens are named, and many of them by well-known specialists in various groups. There are also a large number of types and paratypes in the collection.

(2) *The Ferguson Beetle Collection.*—This collection was purchased by the Council early in 1928 and was stored in Sydney until its transfer to Canberra in April last. It contains the whole of the beetle collection made by the late Dr. E. W. Ferguson, with the important exception of the group of Phalidurine or Amycterine weevils, on which Dr. Ferguson was the recognized expert ; these he presented to the Macleay Museum. The collection consists of 30 store-boxes of named beetles, including a number of paratypes.

(3) *General Collection made by Officers of the Division.*—The most important parts of this collection are the insects gathered together by Mr. Hill since he first joined the Council, as an entomologist, and the recent collections made by Mr. T. G.

Campbell in Northern Australia. In addition, the other members of the staff have added many insects collected from time to time.

(4) *Donations*—Small but valuable collections have been given during the year by Messrs. W. B. Barnard (moths), E. J. Dumigan (Neuropteroids) and G. H. Hardy (flies).

Summarizing the above, it may be said that the collections now contain the nucleus of representatives of most of the families of insects except in the order Lepidoptera, which is at present very poorly represented.

Dr. G. A. Waterhouse was appointed Curator of the Museum in October last, and resigned his position in April. Since that time he has continued to act in that capacity pending the appointment of a successor.

Mrs. Willings was appointed Entomological Assistant to the Curator in April last, and since that time has been in personal charge of the collections at Canberra. She has thoroughly overhauled all the collections and freed all the boxes from pests.

2. The Library.

Up to the present time, no librarian has been appointed for the Division. Dr. G. A. Waterhouse, Curator of the museum, has had charge of the library work to date. Until accommodation was available in the Temporary Offices at No. 12 Melbourne Buildings, Canberra, no attempt could be made to gather any books together. This work was begun in January last, and the Library at present consists of the following parts :—

(1) *The Froggatt Library.*—The entomological library of Mr. W. W. Froggatt was purchased in April of this year. Its transference shortly afterwards to Canberra may be said to mark the real beginning of the Divisional Library. This library contains a number of valuable books and also most of the papers that have been written on Australian economic entomology.

(2) *Portion of the Late Mr. C. Hedley's Library.*—A donation by Mrs. Hedley from her late husband's library includes a number of sets of Proceedings of Scientific Societies.

(3) *Books on Loan from the Library of the Council's Head-quarters in Melbourne.*—Most of the entomological volumes in the Head-quarters Library have been forwarded to Canberra on loan.

(4) *Smaller Donations.*—A number of useful separates have been received from the duplicates of the Australian Museum Library, from the Linnean Society of New South Wales and from Dr. Tillyard's library.

The present policy is to build up the library steadily—(*a*) by the purchase of libraries, text-books and periodicals, (*b*) by a wide list of exchanges between the leading entomological workers all over the world and the research staff of the Division, and (*c*) by the exchange of publications with other official organizations which embrace entomology.

The Commonwealth Library at Canberra is co-operating with this Division by purchasing expensive scientific publications and making them available to us for scientific use. The first of such publications obtained is the *Genera Insectorum*, parts 1–182 complete. We have to thank Mr. Binns, Commonwealth Librarian, for much kindly assistance in library matters.

Since her appointment in April last, Mrs. Willings has arranged the whole of the present library on the steel shelving provided, so that its classification and cataloguing can proceed without interruption as soon as the laboratories are completed.

BY AUTHORITY.

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PAMPHLET No. 16

COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

THE WORK OF THE

DIVISION OF ANIMAL NUTRITION

FOR THE YEAR 1928-29

By

Professor T. BRAILSFORD ROBERTSON, Ph.D., D.Sc.

Chief of the Division

MELBOURNE, 1929

By Authority:

H. J. Green, Government Printer, Melbourne.

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CONTENTS.

The Work of the Division of Animal Nutrition for the Year 1928-29.*

By Professor T. Brailsford Robertson, Ph.D., D.Sc., Chief of the Division.

1. GENERAL.

The Division of Animal Nutrition was created in February, 1927, by the appointment of a Chief of the Division and certain members of the staff. Since investigations on problems relating to animal nutrition, and particularly on the utilization of phosphoric acid by animals, had been in progress in the Department of Biochemistry of the University of Adelaide for some years previously, a small staff was available of people already experienced in this type of work. It seemed advisable, therefore, to inaugurate the Division by extending the nucleus of work and personnel thus available, and the Division was accordingly centred at Adelaide. The Council of the University of Adelaide very generously agreed to render available to the Commonwealth Council for Scientific and Industrial Research sufficient land upon their own property to accommodate the laboratories of the Division, while the Commonwealth Council for Scientific and Industrial Research on its side undertook to render space and materials available for the expansion and continuation of the work of the Animal Products Research Foundation, under which the researches on nutrition then in progress at the University of Adelaide had been conducted. The University and the Director of the Waite Institute furthermore made available to the Council sufficient land at the Waite Institute for the erection of yards for sheep and a room to accommodate the respiration calorimeter.

So far as that portion of the work of the Division which is done at Adelaide is concerned, therefore, it represents a collaborative enterprise on the part of the Commonwealth Council for Scientific and Industrial Research and the University of Adelaide. The laboratory work of the Division is carried out in a building erected by the Commonwealth Council upon the University grounds, and in this building, besides the staff of the Division, there is accommodated the chemist appointed by the Animal Products Research Foundation of the University of Adelaide for the continuation of researches on animal nutrition under the terms of the Foundation. The work carried out under the Foundation is correlated with the work of the Division in such a way as to supplement it. Experimental work upon sheep is being conducted at the Waite Institute by members of the staff of the Division.

On the other hand, the work upon sheep which is being conducted at Adelaide represents only a small proportion of the experimental work which is actually being carried out. At the Waite Institute, it is proposed to carry out experiments of such a nature that it is not feasible to undertake or control them properly upon the properties of sheep owners. These are experiments of a tentative character designed to acquire information to direct our experiments of a more immediate practical

* Typescript received 14th August, 1929.

character. These latter are being carried out at field-stations which it is proposed ultimately to establish in most of the leading pastoral areas in Australia. The field-stations which have been established to date are situated at "Niawanda," near Beaufort, Western Victoria (opened February, 1928), "Kolendo," west of Port Augusta, South Australia (opened July, 1928), "Keytah," near Moree, in Northern New South Wales (opened July, 1928), "Meteor Downs," near Springsure, Central Queensland (opened December, 1928), and at "Dismal Swamp," near Mount Gambier, in the south-eastern district of South Australia (opened July, 1929).

These field-stations are made the centres for an extensive survey of the physical, chemical, and biological characteristics of the surroundings in which the sheep live. The general arrangement is that the owner sets aside a certain number of ewes in lamb, from the lambs of which we select the number that we require for observation or experiment. The growth of these lambs is followed week by week during the first seven months after birth, and fortnightly thereafter, the lambs being weighed upon weighing machines provided by the Division. From each field-station specimens are collected for examination at the laboratories of the Division or for submission to other authorities for examination by them. Thyroid glands, bones, and fodder plants are sent to the laboratories of the Division for chemical examination, samples of soils are forwarded to the Soils Division of the Waite Institute, and are collected under the direction of Professor J. A. Prescott. It is hoped that we will be in a position later on to similarly make botanical collections for submission to the Division of Economic Botany.

The principal investigations which we have undertaken relate, in the main, to the utilization and availability of those two components of the diet which our present experience leads us to suppose may most generally be deficient or unsatisfactory in many pastoral areas in Australia. Those are phosphoric acid on the one hand and protein on the other. The soils of very large areas of Australia are notoriously deficient in phosphoric acid, and these areas embrace many of the most important pastoral districts. In addition to these, in many important pastoral districts the quality or value of the feed available to animals undergoes remarkable fluctuation at different seasons of the year, and for this reason the carrying capacity of the land is often far less than would be possible at the best season of the year. The consequence is that the pasture fails to improve with stocking to the extent that it should do so. During the season of abundance grasses and weeds grow virtually unchecked, and their nutritive value is therefore largely lost, and, moreover, the nutritive value of the feed deteriorates as it ripens. The losses are therefore twofold. A large amount of feed is never utilized, and the feed that is consumed is of lower nutritive value than it would be if it were kept closely cropped. Finally, the seeds, burrs, and so forth produced by the ripened plants constitute a serious handicap to the welfare of the sheep and deteriorate the quality of the wool.

It appears very probable that in the majority of cases the chief deficiency in the season of least abundance is protein, and in connexion with this we are concerned not only with the quantity of protein available, but its quality. It is well-known to biological chemists that equal quantities of different proteins are not of equal value in supporting the growth and nutrition of animals, and this becomes particularly the case when the proteins are needed to produce tissues or products of an exceptional composition, such as wool. Our investigations upon proteins of fodder plants, therefore, have taken the direction, primarily, of investigating the quality of the protein available and of endeavouring to correct the deficiency during the season of hardship, by administering protein concentrates which, from a chemical point of view, should be of high nutritional value for the production of wool.

The laboratories of the Division were completed in October, 1928, and officially opened by the Prime Minister on 22nd October. An account of the building and the uses to which the various laboratories are put was contained in the *Journal of the Council for Scientific and Industrial Research*, November, 1928.

2. INDIVIDUAL INVESTIGATIONS.

(1) At the Laboratories of the Division.

(*a*) *Analysis of Grasses and other Fodder Plants.*—The initial work of the Division during 1927–28 had shown that wool fibre, which is a protein, is of very unusual composition, containing as it does a very high proportion of the sulphur-containing amino acid, cystine. As a result, the production of wool must impose a very especial demand upon the nutrition of sheep, for, since wool contains 13 per cent. of cystine, while fodder protein and flesh protein contain on the average only a little over 1 per cent., it must be necessary, in order to produce 1 lb. of wool fibre, for the sheep to consume not less than 12 lb. of fodder protein. The production of an average fleece would therefore entail a consumption of 72 lb. of fodder protein during the year before any was available for the building of the carcase. No animal can synthesize cystine. It must be obtained preformed from the proteins in the fodder. Furthermore, no animal, excepting those producing very large quantities of hair or wool, experiences anything like this need for cystine. It appeared very probable, therefore, that cystine might become in certain districts a limiting factor in the production of wool. For this reason, it appeared to be essential to ascertain the cystine content and, generally speaking, the amino acid composition of the proteins contained in the fodder plants most commonly used in Australia.

Bulk samples of these fodder plants have been collected, through the kind assistance of the owners of our various field-stations and others who have generously given us facilities for collecting these specimens, and the preparation of these samples for analysis is at present under way. The process is very tedious and lengthy, because it is necessary not only to subject these proteins to chemical examination, but also to test their value for supporting growth upon animals. As protein is never a very abundant constituent of plants, the samples required to isolate the amount of protein needed are very large. In general, over 2 cwt. of each plant is required. It is difficult to find any plant growing in the field in sufficient purity to enable the collector to obtain this amount without contamination with other species, and in each case there has been the preliminary difficulty of ascertaining a situation which facilitated the collection. The collection itself has frequently proved to be a tedious matter. For example, our sample of *Danthonia* was cut by hand with shears by our field officer at "Niawanda." The next difficulty with which we are faced is that it has hitherto been considered impossible to isolate the proteins quantitatively from plants, and we have had to devise a method not hitherto employed elsewhere to meet this difficulty. The method itself is not simple to carry out, and the great pressure of other work which has fallen upon the Division has prevented us from making such rapid progress in this part of our investigations as we had hoped. The work is proceeding slowly, however, and the first opportunity will be taken to relieve members of the staff of other work so as to enable them to concentrate upon this problem.

(*b*) *Investigation of Protein Concentrates suitable for the Promotion of the Growth of Wool.*—In view of our knowledge of the peculiar requirements imposed upon the nutrition of sheep by the production of wool, we have sought in many directions for proteins which are available, or might become available on the market, which would relieve the sheep of some of the strain of wool production by conveying to them an exceptionally high proportion of cystine. Unfortunately, proteins of this character are very rare. The protein, fibrin, which forms the solid portion of clotted blood, is unusually rich in cystine, containing 3.7 per cent.; consequently all food preparations rich in blood are also rich in cystine. Blood meal, however, is not in every respect an ideal food for the purpose. In the first place, the protein present does not consist exclusively of fibrin, and, consequently, the percentage of cystine contained in dried blood meal does not contain the value found in fibrin. It is usually, however, in the neighbourhood of 3 per cent., and blood meal is therefore equivalent to three times its weight of the average type of fodder protein. Blood meal is, however, somewhat expensive, especially if prepared with due care to avoid contamination such as might render it liable to putrefaction when stored, or might cause irritation of the mucous membrane of the alimentary tract. A better source of cystine might be yeast, which we have found to contain 4 per cent. of cystine. Unfortunately, the yeast at present available in Australia is brewer's yeast, in which a high proportion of the bitter principles of hops render the material distasteful to sheep. We have, however, got into touch with the Australian National Power Alcohol Company, whose distilleries are situated at Sarina in Northern Queensland, and they are contemplating installing driers for the preparation of dried yeast at their distilleries. The yeast thus prepared should be highly palatable, and when this becomes available we will be in a position to make an extended trial of its value.

Wool and hair and the related substances, horns and hoofs, are of course particularly high in cystine, and considerable wastage of these materials is available at slaughter-houses. Unfortunately, they are indigestible, and therefore unassimilable by animals. We have ascertained, however, that if they are subjected to partial hydrolysis by hydrochloric acid at high temperatures, these materials can be reduced to liquid form, and our experiments at the Waite Institute, to which reference will be made later, have established the fact that the cystine in such preparations is assimilable and utilizable for the production of wool. It may be of interest to note in passing that in the reduction of these materials to a soluble form, care should be taken to avoid racemization of the cystine. We find that a maximum proportion of unaltered cystine can be obtained provided the concentration of acid is kept at a minimum and hydrolysis accelerated rather by raising the temperature than by increasing the acid concentration. We are employing 10 per cent. hydrochloric acid (33 per cent. by volume of concentrated hydrochloric acid) in the proportion of 1 part of hair refuse to 4 parts of the diluted acid, at the temperature produced by pressure steam of 20 lb. to the square inch, for 1 hour. A slaughter-house product containing a proportion of materials derived in this way from hair, horn, and hoof refuse has indeed been rendered available, and its value as an addendum to the diet of sheep is being tested at our suggestion by Mr. E. D. Ogilvie, at "Ilparran," near Glen Innes, in northern New South Wales, and by Mr. D. E. Donkin, at "Meteor Downs," near Springsure. in Queensland. The preparation available upon the market is guaranteed to contain not less than 3 per cent. of cystine. It is thus equal to blood meal in value, and it appears probable that it can be prepared more cheaply and in a more palatable and digestible form than blood meal.

The discovery of these facts, however, has not ended our search, for protein concentrates may prove of value from the point of view of cystine content. We have ascertained that the juices of plants of the *Ficus* group contain an extraordinarily high proportion of cystine. Unfortunately, it is not very easy to see at the present moment how these could be rendered available commercially upon an economic scale. The percentage of cystine is, however, so very high, often exceeding that present in wool itself, that it becomes of great importance to seek among related plants for one which might become an economic source of cystine. In this connexion it occurred to us that all of the *Ficus* group are rubber-producing plants, and that the presence of the high proportion of cystine might be associated with, and indeed a necessary adjunct for, the production of rubber. There are definite chemical reasons for entertaining this supposition. Cystine readily forms compounds which in living tissues act as powerful reducing agents. The production of rubber, presumably from an originally carbohydrate source, would involve very extensive reduction, and this may be rendered possible by cystine compounds of the character of those to which I have alluded.

It accordingly appeared of importance to investigate the serum left after the removal of rubber from the latex of commercial rubber-producing plants, and, consequently, during the recent visit of Sir Eric Geddes to Australia, he was approached with a view to enlisting the co-operation of the Dunlop Plantations in this investigation. Sir Eric Geddes took a very kindly interest in our problem, and was also good enough to suggest to us that the seeds of the rubber plants might also prove worthy of our attention as a possible food material of value from our point of view. Through the kind assistance of Sir Eric Geddes, we have already obtained from Malacca a shipment of 50 gallons of rubber latex from which the rubber has been removed in the usual manner by coagulation with acetic acid. We have also been promised samples of latex from which the rubber has been removed by the new centrifugal method, and also bulk samples of rubber seeds. Our examination of the latex has not yet proceeded sufficiently far to enable us to gain any idea whether a utilizable product can be obtained from it, but we have definitely found that the cystine content of this material is, like that of the latices of the *Ficus* species, extremely high.

It would be difficult to over-estimate the importance of a thorough survey of all the various botanical groups with a view to obtaining a clearer view of the distribution of cystine-rich materials in nature. With our other work we cannot contemplate such a survey at the present time, but when opportunities present themselves we will from time to time make observations of this character, which, with the co-operation of the Division of Economic Botany, might ultimately yield a preliminary outline of the extensive information which we desire.

In this connexion, attention should be called to the fact that protein concentrates high in biological value for the production of wool, that is containing the requisite amino acids in more nearly the correct proportions for producing wool, may be utilized for the apparently paradoxical purpose of reducing the protein intake of the animals. It has increasingly been observed, following upon the enrichment of pasture land by top-dressing and planting with clover, that numerous troubles make their appearance among the sheep which are apparently attributable to dietary too high in proteins, particularly the condition known as "pulpy kidney," and I am informed also by those qualified to express an opinion upon the subject that the braxy-like disease occurring in Western Australia may possibly be associated with a protein-rich dietary. A diet high in protein has this advantage for the sheep that it renders available a sufficient supply of cystine to furnish the needs of production of wool and carcase as well, but incidentally it must also furnish a tremendous excess of other amino acids. If part of the protein in the diet could be replaced by a protein richer in cystine, the same total intake of cystine might be achieved upon a lower nitrogen plane. What seems at first sight anomalous may, nevertheless, prove true, that it may be possible to diminish the protein intake of sheep by administering to them a suitable protein concentrate. In this direction, much research might be done, especially in those parts of Australia where sheep are run in connexion with farming, and consequently receive a higher proportion of concentrated foodstuffs than sheep that are run upon uncultivated pasture. There appears to be a particular opportunity for studying this aspect of our problem in the south-western district of Western Australia.

(*c*) *Estimation of Wool Yield.*—As stated in my reports to the Council under date of 13th December, 1928, and 22nd March, 1929, work has been carried out upon a method of estimating wool yield by chemical methods. Samples have been taken and prepared for analysis, but the analyses have not yet been carried out. Members of our staff have been too fully engaged with other problems to complete this work. We are confident, however, that the method, although perhaps of no great practical utility from the standpoint of graziers or manufacturers, will prove of definite value in accurately controlled investigations upon the relationship of diet to wool production.

(*d*) *Estimation of Phosphoric Acid in Tissue.*—The phosphoric acid in animal tissues is present in the form of various compounds which find their counterpart in plant tissues. Part of the phosphoric acid is present as soluble phosphates, that is combined with sodium or potassium, or insoluble phosphate when combined with calcium and deposited as tricalcic phosphate in bones. Another portion of the phosphoric acid is present in combination with fats forming the class of fats known as phospholipins. A third portion of the phosphoric acid, and one which is very important in the growth of animals, is present in a very complex compound known as nucleic acid, because the greater part of it is situated in the nuclei of the cells.

In seeking to obtain a comprehensive knowledge of the factors involved in the utilization of phosphoric acid, it would obviously be pre-requisite to account accurately for all the phosphoric acid assimilated. That is, one should be in a position to say that such and such a proportion of the phosphoric acid had been utilized by the animal in one direction, another proportion in another direction, and so forth. This form of dietetic accountancy has hitherto been impossible for phosphoric acid because no method has been available for the quantitative estimation of nucleic acid, and a proportion of the phosphoric acid must therefore inevitably escape our addition, and a successful balance would not be struck between intake and retention beyond the mere assumption that that which had been taken in and had not been eliminated must be in the body somewhere. During the past two years, work has been going on in the laboratories of the Division and in the Biochemistry Department of the University of Adelaide, aiming at the quantitative estimation of nucleic acid, and the work has so far proceeded that we are now in a position to estimate nucleic acid with a very close approximation to accuracy. Methods of estimating inorganic phosphates and phospholipins are well known and standardized, so that with a method in our hands enabling us to estimate nucleic acid we ought to be able to balance the phosphoric acid account in investigations upon the assimilation of this substance by animals.

Initial experiments of this character are already in process of being carried out, and we are engaged in comparing the distribution of phosphoric acid in the various tissues of lambs at birth obtained from our sheep at the Waite Institute with the distribution of phosphoric acid in the various tissues of the ewes from which these lambs were obtained. These animals have been fed upon a diet which should be abundant in phosphoric acid, since the pasture upon which they have been fed has generally been top-dressed, and they have obtained supplementary food which is also rich in phosphoric acid. We are carrying out these analyses for the following purposes :—

(i) To obtain experience in the practical conduct of such analyses upon whole animals.

(ii) To ascertain what may probably be regarded as the normal distribution of phosphoric acid in the bodies of well-fed animals.

(iii) To ascertain the effects of age upon phosphoric acid distribution.

We next intend to apply these methods to the investigation of the efficacy of various licks for supplying phosphoric acid deficiency encountered in the pasture. For this purpose we will utilize animals obtained from our newly-established field-station at "Dismal Swamp," near Mount Gambier. At this field-station, as will be more fully detailed below, we are planning to administer to the animals various licks rich in different types of phosphoric acid compounds. At about six months of age, a lamb from each group will be brought up to the laboratory, slaughtered there, its tissues perfused through the large blood vessels with saline solution to remove the blood from all the tissues, and the tissues thus freed from blood will be subjected to analysis.

The net outcome of all of these experiments, if carried out according to programme, will be a record of not less than 2,000 analytical estimations, from which we should be able to deduce much regarding the distribution of phosphoric acid in the animal body under conditions of relative abundance and deficiency, and we should also obtain an accurate idea of the value of various licks in assisting the animal to approximate to the condition of normal animals in receipt of nourishment containing abundance of this requisite.

(*e*) *Analysis of Bones*.—From our various field-stations, and also as a result of tours undertaken by myself and members of my staff, a very comprehensive collection of bones has been obtained from a variety of pastoral areas in Australia. Our practice has always been to take the same bones, namely four rib bones, beginning with the fourth rib bone counting from the last floating rib. The rib bones are disarticulated at both ends so that the entire bone is obtained, and the proportion of marrow to bone should be the same in each if the bones are alike in development. It must be emphasized that in almost all of our work, analytical methods are not yet completely tested or accurately standardized. The beginning of every investigation of a biochemical character generally entails a fresh attempt to attain greater accuracy in analyses. This was also the case in the present process, and much time was spent by Mr. Thomas in reviewing existing methods of analysis, checking and adapting them, and attaining greater accuracy. The analytical methods employed in this problem are particularly important, because the differences in the composition of bones of sheep fed upon satisfactory and deficient pasture are quite small, although undoubtedly of the very greatest significance provided they can be definitely established. The attempt of the tissues is always to lay down tricalcic phosphate in bones, and the attempt is generally successful. A failure amounting to only a few per cent. of the total probably indicates the very greatest difficulties experienced by the tissues in acquiring the necessary materials to manufacture normal bones. We have therefore to deal with, and attach a significance to, differences which generally amount to only a few per cent. of the total quantities estimated, and analytical methods must be sufficiently accurate to reveal these small differences with certainty. Such methods have been found and a most extensive series of analyses undertaken by Mr. Thomas. Analysis of the first 100 samples is approaching completion, and from them we should obtain a preliminary idea of the correlation between bone composition and the geology and soils of the districts from which they were obtained, and the physical characteristics of the bones themselves.

(*f*) *Iodine in Thyroid Glands*.—The survey of the iodine content in the thyroid glands of sheep in different parts of Australia falls into two parts. The one consists of the analysis of glands obtained from widely scattered areas, only one or a few glands being analysed from each locality. This should serve to reveal any districts which should chance to be notably deficient in iodine. The other consists of the analysis of large numbers of glands from a few districts in which our field-stations are situated. These analyses should enable us to estimate the variability of iodine content in the glands of individual sheep, and thus to estimate the degree of significance to be attached to individual or few analyses from other districts, and it should also enable us to correlate the variations in iodine content with variations in the condition of the sheep and the quality of the wool. Latterly, all our thyroid gland specimens have been collected, together with a staple of wool from the shoulder of the sheep, with the object of ultimately sending these to the laboratories of the British Research Association for the Woollen and Worsted Industries, with a view to obtaining a report from them, if this can be arranged, on the physical qualities of the wool. With a simultaneous knowledge of the accurately measurable physical qualities of the wool and the iodine content of the thyroid glands, any correlation between the two should stand out clearly. There is reason to suspect that such correlation may occur, because in other animals the thyroid gland is known to exercise considerable influence upon the growth of hair.

The first series of analyses at a single field-station, near Beaufort, Western District, Victoria, has been completed. These analyses were carried out by Miss M. C. Dawbarn, the chemist appointed by the Animal Products Research Foundation of the University of Adelaide, who has been provided with space and materials for her work in the laboratories of the Division. The results confirm the observation which has been made in America that the iodine content of thyroid glands is subject to seasonal fluctuation. Those collected in the late spring and early summer months, September, October, and November, contain considerably less iodine than those which were collected in the preceding six months. The confirmation of this observation in Australia is of special interest, because, in the first place, our seasons in Australia are reversed, and the observation of a decrease in iodine content in early summer in the Southern as well as the Northern hemisphere definitely correlates the seasonal change with the climate or the pasture. and, in the second place, the iodine content of the thyroid glands of the sheep in western Victoria is very much higher than the iodine content of the thyroid glands investigated from this point of view in America. A very large proportion of the United States is deficient in iodine ; Australia seems to have escaped this deficiency and to be singularly well endowed with iodine in its pastures. Yet, although iodine is abundant in the pastures in western Victoria, the same seasonal variation is shown by these sheep in receipt of abundance as is shown by sheep in America subject to deprivation. This almost suggests that the fall of iodine in spring may be due not so much to the inability of the sheep to obtain iodine from the pasture as to some change in the animals themselves which diminishes their power of retaining iodine in the thyroid gland.

It will be especially interesting to compare these results with those which we will subsequently obtain from thyroid glands collected at "Meteor Downs," near Springsure, Central Queensland, for this is a region of summer rainfall, and if a seasonal variation is found there we will be able to ascertain whether it is correlated with rainfall and the period of most intense growth of the pasture, or, rather, with the temperature of the surroundings.

The methods for the estimation of iodine in thyroid glands are well known and standardized. We have repeated the checking and standardization of the most frequently used method ourselves, and have satisfied ourselves of its accuracy. From this point, the work became of an exceedingly routine character, simply involving the repetition of stereotyped analyses.

In recent years, much publicity has been given all over the world to results obtained in America and in some parts of Europe from the administration of iodine to animals. Particularly striking are the results obtained in the middle west of America where iodine is extraordinarily deficient. In Australian newspapers and pastoral journals as well, these results are frequently quoted as if they applied with equal significance to all parts of Australia, and the impression has grown up among many pastoralists that iodine is universally necessary to add to the diet, and that the effects to be expected from its inclusion in a lick are little short of miraculous. Our results do not in the least encourage this view. On the contrary, it appears that the greater part of the pastoral areas of Australia are abundantly supplied with iodine. In the south-eastern part of South Australia, for example, where the use of iodized licks has recently been very strongly urged by firms having a commercial interest in their distribution, we have found that animals in receipt of no licks have thyroids containing the highest proportion of iodine yet reported from any portion of the world. Obviously, the propaganda to induce pastoralists in that district to add iodine to their licks is useless and mischievous. We have, in fact, only found two spots upon the mainland and one in Tasmania where any degree of iodine deficiency meriting attention may be suspected to occur, and even there the lowest results we have obtained are three times as high as the lowest results obtained in America. In order to combat the general propaganda designed to induce pastoralists to incorporate this expensive substance in their licks, I thought it advisable to publish a brief statement in *The Pastoral Review*, dated 16th May, 1929, and it is to be hoped that this may have some effect in discouraging the indiscriminate use of potassium iodide. It should nevertheless be admitted that our survey is as yet far from complete, and areas may yet be found in Australia where serious iodine deficiency must be combated.

(2) Work at the Waite Institute.

(*a*) *The Maximal Growth of Merino Sheep.*—The first problem which we undertook at the Waite Institute, and also the simplest, was to ascertain the maximum growth attainable by the merino sheep under optimal conditions. There is no direct economic value in such a determination, but we desired to undertake it with a view to providing ourselves with a standard measure from which we could estimate the degree of shortcoming displayed by sheep under different natural conditions. Through the generosity of Mr. Walter Hawker, of "Anama" Station, near Clare, in South Australia, we obtained a number of sheep of the "Anama" blood, from which we have bred lambs which we have brought up under luxurious conditions of nutrition. They have been fed upon top-dressed pasture, and every day their diet has been further supplemented by the addition of linseed meal and oats. They have, in addition, been in receipt of a salt lick containing all those minerals which are found, upon analysis, to be present in the tissues of sheep, so that no lack of any sort should have been experienced by these animals. Extraordinary growth was obtained, greatly exceeding that obtained at any of our field-stations. Nevertheless, it was of interest to note that, despite the artificial feeding designed to supplement the pasture, the animals have shown seasonal fluctuation in growth, reflecting that displayed by animals pastured under natural conditions and in receipt of no addenda. This may be due to two reasons. In the first place, cold weather in itself imposes an extra strain upon the nutrition of any animal, since nourishment is required to replace the heat lost from the body, but we have the impression that the slackening of growth in the early part of the winter was greater than could be accounted for in this way, and it suggests that materials are available from fresh pasture which cannot be supplied by artificial feeding or the addition of mineral supplements to the diet. It must be emphasized, however, that this remains merely an impression, and that we have no quantitative proof of its accuracy.

(*b*) *The Growth of Wool on a Diet Deficient in Cystine, and on the Same Diet Supplemented by Wool Hydrolysate.*—In the previous season, 1927–28, we endeavoured to ascertain whether the production of wool by sheep could be stimulated by the administration of cystine derived from the hydrolysis of waste wool. This experiment was undertaken, not so much from the point of view that it might be directly applied to practical conditions, as that it might form evidence of the correctness or otherwise of the general supposition upon which we were proceeding that cystine might be the limiting factor in the production of wool under natural conditions. The results were negative, as no definite difference could be established between the fleeces of those animals which had received addition of cystine to their diet and the fleeces of those animals which had not received such addition. At the time, we were inclined to attribute this failure to changes induced in the cystine by the process of hydrolysis and separation, and, indeed, part of the failure may have been attributable to this cause, since we know that nearly half the cystine is transformed during isolation into a form which cannot be utilized by animals and is excreted unchanged in the urine. Nevertheless, our later investigations carried out during the current season have shown that there was another cause for failure in our experiments, namely, that the pasture upon which the animals were fed was itself too rich in cystine to permit our relatively small addendum to make any perceptible difference. In other words, the cystine that we added to the diet was but a small proportion to the whole of the cystine they were obtaining, and the effects, if any, would necessarily be correspondingly small. The differences for which we were seeking were swamped in the magnitude of the whole supply.

With the current season, we started in a different way. In the first place, instead of aiming to supply the animals with pure cystine, we sought to furnish it to them in such a form as to be still combined with other amino acids, not in such complex combination as in wool itself, but in products obtained from the incomplete digestion of wool by acid. In this way, we minimized the chances of destroying the utilizability of the cystine by changes incurred during the process of hydrolysis. In the second place we took care, upon this occasion, to ensure that the diet was as low in cystine as we could reasonably secure without injury to the animals, and our results have shown that care is necessary in controlling the basic diet and insuring its definite deficiency in cystine in order to obtain the most striking results. We may say, however, as a result of our experiments during this year, that the effects of administering the partially-hydrolyzed wool have far exceeded our anticipations, and we now anticipate that at shearing the difference between the fleeces from the animals deprived of cystine and those to whom cystine has been administered in this form will prove to be of a most striking character.

These experiments appear to us to substantiate beyond doubt the view that the quality of the protein, that is, the proportions of various amino acids administered to the animals, is of the utmost importance in determining the yield and quality of wool. The bearing of this experiment upon our search for suitable concentrates to supplement the diet of sheep during those seasons of the year when the pasture is deficient in nourishment will be obvious, and we are encouraged to continue the search for concentrates rich in those amino acids which are exceptionally abundant in wool.

(c) *The Production and Prevention of " Break " in Wool.*—In our experiments we have sought to imitate those conditions of the natural pasture which occasionally result in the production of a definite " break " in wool. By " break " is meant a sudden change in the diameter of the wool fibre, usually resulting from the thinning down of the fibre due to drought conditions, followed by a sudden thickening due to the springing up of a quantity of fresh herbage following upon rain. The disadvantage of " break " from the standpoint of the manufacturer is that the two parts of the wool staple are not suitable for employment upon the same machine, and if the staple be divided at the point of " break " the portions remaining are too short to produce the best fabrics on the machines employed in spinning and weaving. Wool which exhibits a " break " is therefore of very low value in the market.

Much of the damage to the value of wool due to "break" might be obviated if the change in fibre diameter could be rendered more gradual, and this might conceivably be done if the pastoralist could foresee the probability of "break" occurring at a certain season in his sheep and forestall the occurrence by supplying them with a supplement exceptionally rich in cystine, permitting them to increase the diameter of the wool fibre gradually until the flush season found them prepared to continue this growth.

By feeding sheep on a diet of chaff, imitating the feed available under drought conditions, and then, after a couple of months, transferring them to rich feed, supplemented by lucerne, definite "break" is readily obtained. We have sought to prevent this by spraying wool hydrolysate upon the chaff, and have succeeded so far that in many instances there is no longer a "break" in the wool, although the wool remains somewhat tender. We have thought that by this means sheep accustomed to take licks could be treated to prevent the appearance of "break" in the wool following upon drought conditions. In many areas the pastoralist would be aware that "break" was likely to occur after a period of scarcity at a definite season of the year, and for a couple of months previously, he could incorporate wool hydrolysate in the lick. This is quite feasible economically, because the whole growth for the twelve months will be rendered more valuable by the addition of the supplement for a period possibly not exceeding two months, and the supplement itself, wool hydrolysate, can be prepared from the poorer qualities of wool. Should we ever succeed in obtaining concentrates as high in cystine content as wool itself, then, of course, these can be substituted for the hydrolysate.

We had hoped to be able to utilize the prevailing drought conditions in the upper north of South Australia as a means of an extended practical test of this method, but I have not yet been able to ascertain a favorable assemblage of conditions for a trial. In the first place, pastoralists in the upper north of South Australia are not accustomed to administer licks to their sheep, since no known mineral deficiency occurs in this district. Sheep are, therefore, not accustomed to seek for licks, and could not readily be educated to do so. It might be possible to overcome this by adding hydrolysate to their water. During the present winter light falls of rain have occurred at Kolendo, where our field-station is situated, which have freshened up the feed and brought forward a small growth largely checked by the cold weather and insufficiency of further rain, but still sufficient to maintain the diameter of the wool fibre, so that if rain falls in the spring no definite "break" is likely to occur. We will seize the first opportunity which presents itself in any State for giving this method of preventing "break" a thorough trial.

(*d*) *Calorimeter Studies*.—In the erection of the respiration calorimeter at the Waite Institute, we were generously assisted by the advice and experience of Dr. F. G. Benedict, who is the Director of the Nutrition Laboratory of the Carnegie Institute in Boston, U.S.A. With the assistance of an experienced mechanic, we designed and assembled the calorimeter to conform as closely as possible to the model employed by Dr. Benedict. The principle of the instrument is to measure the total output of carbon dioxide by an animal during the specified period of time when it is in a fasting condition and at rest. Simultaneously, the consumption of oxygen is measured. The ratio of the two yields important information as to the type of foodstuffs mainly undergoing metabolism in the body, while the total carbon dioxide output yields a measure of the total materials burnt in the body. From these figures obtained under fasting conditions, one obtains a measure of the minimal requirement of food for the maintenance of the animal. It is obvious that sufficient food must be supplied to furnish an equal amount of carbon dioxide when burnt to that which is given out by the animal at rest and under starvation conditions. If growth is to be attained, or the animal undergoes exertion, the allowance must of course be increased, but in this way we get a measure of the basic minimal requirement.

Such a measure is of exceedingly great importance as a guide in the making up of recipes for hand-feeding in drought. I am aware that in some parts of Australia it is considered that hand-feeding during drought is a ruinous practice, while it is regarded as equally certain in other parts of Australia that it can be carried out, if not at a profit, at any rate at a minimum of loss, which is preferable to losing the animals themselves. From my observations, I would say that this difference of opinion is attributable to difference of practice. The practice of hand-feeding in drought has been so improved in Queensland that its value may be regarded as having been established, but the foodstuffs available at one time and place may not be the same as those available at another time and place, and if we have to make a substitution in the recipes recently employed in Queensland, the question is what principle shall we use to guide us in choosing the substitute most likely to yield a mixture of equally nutritive value? To do this we must know what amount of nutrition has to be administered, and then from standard figures already available in many publications we can readily calculate to a sufficient degree of accuracy what amount would be required of each type of fodder substance to supply the energy needed by the animal.

Figures of this kind have already been obtained in America and Europe, but, unfortunately, we cannot apply them directly to Australian conditions. In the first place, the breed of sheep is different. Australian pastoralists have been engaged for over 100 years in attempting to breed drought-resistant animals from merino sheep, and there is every reason to anticipate that our sheep will turn out to have exceptional powers of utilizing food with economy and resisting the influences of starvation. Then again our climate is different, and sheep which must be shedded during the winter in Europe and Northern America are here kept out on pasture. Finally, the diet of our sheep is different, and the diet of which the sheep has previously been in receipt influences, to some extent, the energy output during subsequent starvation. That is to say, the basal requirement of an animal depends to some extent upon the way this requirement is met. In general, the richer the food in protein, the greater will be the basal requirement. Animals fed upon concentrates and leguminous plants rich in protein will be relatively wasteful, while animals fed under hard conditions upon diets poor in protein will be relatively economical in the consumption of energy.

Our preliminary results indicate that, as anticipated, the energy requirements of the Australian merino are lower than those of European sheep, and correspond approximately with the energy content of the maintenance rations ascertained by the feeding experiments of pastoralists in Queensland, among which I may especially mention those of Mr. T. L. Armstrong, of "Corona."

The next step will be to ascertain the requirement for a given amount of growth so that this addendum may be added to the diet of growing lambs, and from a chart which, when we are in possession of the data, will not be at all difficult to construct, it will be possible for a pastoralist to read off at any age of his sheep the amount of food that will be necessary.

Although we have obtained the most essential figure with a sufficient degree of accuracy for application to practical conditions, we are not yet satisfied that the figure is sufficiently accurate from a scientific point of view. We have discovered certain defects in portions of the apparatus that we have employed which we are seeking to remedy by apparatus of a different design. Before publishing our results, we would prefer to be confident that they represent the utmost attainable accuracy in such an investigation, and we are consequently waiting until the newly-designed portions of the apparatus have been procured to repeat our experiments over again and confirm them.

After obtaining these fundamental figures, there will be many problems in calorimetry which it will be of importance to undertake, and there is no doubt that the calorimeter at the Waite Institute will be in pretty constant use for many years to come, beginning with the most fundamental and generally applicable determinations, and passing on to more complex and detailed problems, all of which will ultimately be found to be of economic importance. With this lengthy programme ahead of us, it would be wise to have the services of workers specially trained in this field, and we have suggested to the Trustees of the Science and Industry Endowment Fund that a travelling studentship should be offered to enable some recent graduate of an Australian University to study at Dr. Benedict's laboratory at Boston, and also at Cambridge. I would suggest that such a student should spend a preliminary couple of months here so as to become familiar with the problems which we met with in the practical technique of the work, so that when he goes abroad he will be in a position to seek just that information which we most urgently need.

3. FIELD-STATIONS.

(1) General Policy.

The general policy at our field-stations is to institute a co-operative investigation with the owner. The steps leading up to the establishment of a field-station have generally been somewhat as follows :—

In the first place, information has been sought from individual pastoralists, or more often from pastoralists or graziers associations, as to the nature of the problems met with in the State and the most suitable localities for investigating them. The result of such inquiries is usually to indicate certain areas as suitable centres for investigation. The next step is to find an owner in those areas who would be willing to collaborate in research. The procedure in finding such an owner has varied in different places. In Victoria, Mr. R. G. Beggs, upon whose property our field-station is situated, was indicated by the Executive Committee of the Graziers' Association; in South Australia, the owner of the field-station at "Kolendo" was approached through pastoralists with whom the Chief of the Division happened to be acquainted; in the south-eastern district of South Australia, Mr. Sutton's property was indicated by the Stockowners' Association of South Australia; in New South Wales, Mr. E. D. Ogilvie, owner of "Keytah" station, was indicated by the Graziers' Association; in Queensland, the owner of "Meteor Downs," Mr. D. E. Donkin, was introduced to us by Mr. A. J. N. Gillespie, who has had exceptional experience of pastoral conditions in various parts of Central Queensland.

A suitable owner having been found, he is then consulted as to the problems in his district and his advice is sought as to the most suitable problem to investigate and the best way of undertaking the experiment. In every case, it has been found that the experience of the owner has been of the utmost value in indicating the plan of the experiment, and the purpose at which it should aim. The owner is then asked to set aside a certain number of ewes in lamb from which we select a sufficient number of lambs to yield a growth curve, and also any additional number that may be necessary to perform any experiments undertaken at that station. A field officer is then appointed, but it is especially provided in our agreement with the owner that the field officer's salary shall be mainly paid through the hands of the owner, with the exception of a small retaining fee which is paid to the field officer direct, in order that he may feel that we have a direct claim upon his services. The greater part of the field officer's salary is paid through the owner in order that he may view himself as an employee of the owner and subject to the discipline of the station. The owner is even at liberty, if he thinks fit, to dismiss the field officer provided he undertakes to see that our work will be carried on until we have had reasonable time to replace him. The responsibility for the carrying out of the work is therefore placed ultimately upon the shoulders of the owner, but the Council provides the extra help to carry out the work efficiently. The field officers are chosen, in the first place, on the recommendation of pastoralists, who have been acquainted with them, for their conscientious character and ability in handling sheep. They are given a preliminary training of brief duration, either at the Waite Institute or at a previous field-station, and carry out the measurements, observations, and collection of specimens precisely as instructed by the members of the staff of the Division. Occasional visits are paid to each field-station, either by the Chief or the travelling field officer, Mr. Lines, in order to ensure that all directions are being carried out and, at the same time, that they are being executed in a standardized manner so that the results from one field-station may be comparable with those obtained from another. One visit is paid to each field-station by our geological chemist, Mr. R. G. Thomas, who draws up a full report on the geology of the district and at the same time collects samples of soil which are forwarded to the Waite Institute for examination and report.

It is hoped that it will be possible in the future to obtain the services of an agrostologist attached to the Division of Economic Botany, to carry out in a similar way surveys of the botanical characteristics of the districts in which our field-stations are situated. It is hoped, also, that our field-stations may become, to an increasing degree, centres upon which the energies of other Divisions besides that of Nutrition may be focused. At every field-station we have, for example, encountered veterinary problems which we could not overlook, although in most cases these have turned out to be not so much matters requiring research as the dissemination of information. Nevertheless, we have already found it advisable to plan experiments at certain field-stations to demonstrate to the owner the value of treatments recommended by appropriate authorities. The nutritional and veterinary aspects cannot in fact be separated, for if we consider the situation in any area in which the value of the pasture undergoes great fluctuation during the year, so that much of the pasture remains unutilized and is never closely cropped, anything which under such conditions would increase the stocking capacity, should also improve the quality and nutritive value of the pasture. Whether this be accomplished by eradicating worms or blow-fly, or by providing a protein supplement of mineral licks, is of little consequence, the major objective being to secure denser stocking and consequent progressive improvement of the pasture. Improvement of nutrition may, therefore, be brought about, in the long run, through the eradication of parasites just as, conversely, improvement of nutrition may lead to a greater resistance to parasites on the part of the animals.

Frequently, the field-stations will prove to be in situations of interest to other Divisions, for the same reason that they are of interest to the Division of Animal Nutrition, namely, that they are situated in places which are representative of large areas of pastoral country. The problems that affect our field-stations will therefore be problems as a rule widely dispersed over important pastoral areas. They may, therefore, prove to be convenient centres for the investigation of veterinary, entomological, and economic botanical problems. While it is advisable that all such investigations should be carried out under the direct control of the Divisions concerned, it will be necessary that, in each case, the approach of the owner for permission to carry out the work, or for an officer to visit the station, should be made through the Chief of the Division of Animal Nutrition in order that the owner may feel that he knows from whom to expect requests and to whom to complain in case anything happens which meets with his disapproval. The field-stations should, therefore, be regarded, in the first place, as being primarily instituted for the investigation of animal nutrition; in the second place, as foci for some of the work of other Divisions; and the channel of communication between the owner and all Divisions should be the Chief of the Division of Animal Nutrition. The same principle would apply in case similar stations were established by other Divisions and the courtesy extended of permitting the Division of Animal Nutrition to engage in researches upon them. In that case, whatever Division had established the station would remain the channel of communication with the owner.

In recent months, many inquiries have been received in regard to the possibility of establishing additional field-stations. It has been suggested that field-stations should be established in the Kimberley and south-western districts of Western Australia, in Tasmania, and at other points in New South Wales besides Moree. It is indeed quite clear that one field-station in the whole of New South Wales is an inadequate allowance. New South Wales contains half the sheep in Australia, spread over a very great area representing a great diversity of climatic and geological features. Authority has been asked for the establishment of two more field-stations in New South Wales in the current financial year, and two more in the year following, and arrangements have been made for the Chief of the Division to consult with the recently appointed Scientific Advisory Committee of the Graziers' Association of New South Wales early in September, with a view to settling upon appropriate localities for the establishment of these four field-stations. It is hoped that in the financial year 1930–31 it may also be possible to establish field-stations in Western Australia and Tasmania.

The field-stations and the laboratories at Adelaide are to be regarded as mutually dependent aspects of our work. From the laboratory, ideas go out to be tested in the field, from the field problems come in, together with specimens which illustrate them. This give and take; assisted in each case by the co-operation of the most experienced pastoralists, should lead us to obtain results of value to the pastoral community.

It may, furthermore, be pointed out that the field-stations, besides affording valuable centres of research, are also valuable centres for the dissemination of any information we may obtain. Experience shows, I think, that pastoralists in general are reluctant to accept procedures which are recommended by scientific experts who have not had to carry them out under practical conditions, and especially under the rigorous necessity of securing a financial return for their outlay. Pastoralists feel that such advice may possibly be scientific but unpractical. But when they see experiments carried out upon the property of a neighbouring pastoralist of high reputation in his profession, favorably regarded by him, and the results possibly adopted by him, they are eager to seek the same information and to apply it if it has been found successful on the original property. We have shown this to be the case at Springsure, and also in northern New South Wales, and I think we shall experience no difficulty in the future, if we should obtain results of considerable value to the pastoralists, in persuading them of their value and disseminating the information through the medium of our field-stations.

(2) "Kolendo," via Port Augusta, South Australia.

This station, as stated in my reports of 13th December, 1928, and 22nd March, 1929, has been temporarily closed on account of drought prevailing in this district. The drought has partially broken and lambing is expected in August, but it is anticipated that the lambs will be scattered over a wide period of time, and unless satisfactory rains fall in the spring, little more success is to be hoped for than we had last year. To re-open the field-station at this juncture, therefore, would be to risk having to close it down again after the expenditure of money uselessly. We have thought it best to await yet another year in the hope that the seasons may once more become average in character.

(3) "Buln Gherin," now "Niawanda," near Beaufort, Victoria.

The work at this field-station continues to proceed very satisfactorily. To date, our activities here have been mainly devoted to observation and collection of materials. We are satisfied that there is an important problem in the Western District of Victoria, and from analyses collected from the available literature by Mr. Thomas, we strongly suspect that one of the difficulties of this district consists in the deficiency of sulphur in the soils. The question arises as to the best method of attempting to remedy this. At this field-station and upon other properties in the Western District we would like, if we obtain the permission of the owners, to undertake experiments upon top-dressing the soil with sulphur, the point of view being not so much that the percentage of cystine in the proteins in the existing fodder plants will be thereby increased, but that the character of the fodder plants, that is the relative proportions of different kinds of plants, will be altered in such a fashion as to remove the existing handicap from those plants which produce proteins containing the highest proportion of cystine. What we would anticipate would be a progressive change in the character of the herbage comparable with that which is observed after top-dressing with superphosphate, but of a different character. On land which is deficient in phosphorus, all plants which are greedy consumers of phosphorus, that is which produce tissues exceptionally rich in phosphorus, are handicapped in comparison with other plants. When phosphoric acid fertilizers are applied, this handicap is removed, and hence we find that clovers, &c., begin to gain headway upon the grasses. In the same way, if by adding sulphur to the soil, we can remove the handicap imposed upon plants yielding cystine-rich proteins, these may be expected to make headway, but we do not yet know what plants these are, and we therefore cannot assist the process by sowing them or broadcasting seed as is commonly done for the clovers in connexion with top-dressing.

I have hitherto been rather reluctant to recommend owners to try any experiments upon top-dressing with sulphur, because I feared that an over application might have a very deleterious temporary effect upon the pasture plants. I have, however, been in consultation with Professor Prescott on this question, and it is his opinion that top-dressing with sulphur might safely be attempted, and it is my intention in the near future to approach several owners in the Western District to ask them to try this practice upon a small and tentative scale.

(4) "Keytah," Moree, New South Wales.

Work is proceeding satisfactorily at this field-station. The object of this station, besides procuring information concerning the black soil plains in this district, is to compare the growth of lambs in receipt of a lick containing iodine with the growth of lambs in receipt of a lick free from iodine. This district is relatively iodine-deficient. We have obtained thyroids in the neighbourhood of Moree containing as low as 0.1 per cent. of iodine, the average in other parts of Australia being as a rule from 0.5 to 0.7 per cent. The thyroids obtained in this district were also found to be considerably enlarged, indicating that the glands were responding to the deficiency, but although this degree of deficiency has been found, it by no means follows that it is injuring the welfare of the animals to such an extent as to make it economically important to supplement their diet with potassium iodide, and it is in order to obtain information upon this point that we have inaugurated this experiment. It may be stated that the owner of the station, Mr. E. D. Ogilvie, upon receiving my reports concerning thyroid glands collected in that district, was sufficiently satisfied with the importance of the matter to administer to his animals a lick containing added potassium iodide, and in doing this he is upon the safe side, but we felt that it was important to ascertain whether the results achieved were demonstrable in the improvement of the condition of the animals or the yield, condition, or quality of wool. In seeking to attack this problem, we were handicapped by the fact that this district is also deficient in phosphates, and probably in salt, and that it is the custom at "Keytah" to administer a lick containing these materials to all the sheep. To make our iodine-free animals comparable with those receiving iodine, therefore, it was necessary to supply them with a lick containing the same materials as the lick supplied to the other animals, with the sole exception of iodine. This was very difficult to guarantee, because iodine is present as a contamination in very many substances, and it was some considerable time before we could satisfy ourselves that we could compound a lick substantially equivalent to that already given by Mr. Ogilvie, which would certainly not contain appreciable amounts of iodine. In the meanwhile, the ewes from which we expected to derive the lambs to receive the iodine-free lick were pregnant, and we could deprive them of iodine only by depriving them of lick altogether. This procedure was adopted, but by the time the lambs were dropped we had succeeded in compounding a lick virtually free from iodine, and from birth the ewes and lambs were placed upon this lick. There are, therefore, two factors involved in this particular experiment, the one the period of pre-natal deprivation of licks of any kind, the other deprivation of iodine since birth together with the provision of the other mineral requisites. It may prove difficult to distinguish between the effects of these two differences, but we anticipate that the pre-natal effect will shortly be overcome unless deficiency of iodine continues to handicap the animals and thus perpetuate the pre-natal effect. At any rate for whatever cause, the animals at birth produced by the ewes in receipt of no lick, were definitely lighter in weight than those produced by ewes in receipt of the lick employed by Mr. Ogilvie.

As stated in my report of the 22nd March, 1929, the owner of this station, Mr. Ogilvie, is also conducting, under our direction, extensive tests on supplementary feeding with protein concentrates, both at "Keytah" and at "Ilparran," near Glen Innes, New England. At "Keytah" the attempt is being made to utilize flood grass areas where it is known that, without supplements, sheep cannot subsist for long without material loss of condition. By the employment of a protein supplement rich in cystine, it is hoped to enable the sheep to utilize these inferior grasses without loss of condition. In New England, the attempt has been made, with the assistance of a protein concentrate, to raise lambs upon a portion of the property on which this has hitherto been considered impossible. I understand that so far Mr. Ogilvie has been very well pleased with the results he has obtained from employing this concentrate.

(5) "Meteor Downs," Springsure, Central Queensland.

The work at this station is proceeding very satisfactorily. We are here experimenting with blood meal containing 3 per cent. of cystine as a supplementary foodstuff. This blood meal has been especially prepared for us, according to our directions, by the Metropolitan Abattoirs at Adelaide.

At this station, we have 200 lambs, of which 100 are in receipt of the supplement and phosphate lick, the other 100 receiving the lick but no supplement. Both lots of lambs are reported to be doing excellently, but the lambs receiving blood meal are reported to be doing better than the controls. The paddocks upon which these animals are pastured are altered every two or three months so as to ensure even conditions of the two lots in the long run. For the past two or three months, the control lambs have had what has turned out to be the better pasture. Nevertheless, the blood meal lambs are doing at least as well as the controls. Should the administration of blood meal the whole year round lead to an increase of only 20 per cent. in the carrying capacity of the land, it would pay for itself, but the administration of blood meal during the flush season would be economically absurd. We are doing it in the experiment simply because we do not wish to confuse the issue by making any arbitrary choice of the season at which the supplement is administered, but in practice the administration of the supplement might probably be confined to four months of the year, and if a 20 per cent. increase of carrying capacity would pay for the administration of the supplement the whole year round, it will be understood that if the same effect can be obtained in four months, the procedure will be distinctly profitable.

At other field-stations, it is hoped to try out other supplements one by one as they become available. In each case the expense will be slight; it will merely be necessary to provide two paddocks, or possibly a third as a relief paddock, of sufficient size to accommodate 100 lambs each, and to purchase the supplement and compound it with a lick suitable to supplement the mineral deficiencies of the district in so far as these are known.

(6) "Dismal Swamp," near Mount Gambier, South Australia.

Throughout a large proportion of Central and Northern Queensland, in considerable areas of New South Wales and Victoria, in the south-eastern district of South Australia, and over a large proportion of the pastoral areas in Western Australia, phosphoric acid deficiency is known to exist, and in some cases is of a very drastic character. It will be understood, of course, that we view top-dressing with superphosphate as the ideal method of combating phosphoric acid deficiency in the soil, but over a large proportion of the pastoral areas in which such deficiency prevails, the anticipated economic returns are not sufficient to justify the outlay, and in such cases resort must be had to licks. It may be pointed out, however, that in some border-line cases, where the carrying capacity is at present insufficient to justify top-dressing, it is possible that it may be so increased by the employment of licks and the pasture so improved by heavier stocking, that top-dressing may eventually become an economic proposition. In such instances, the employment of licks may be regarded as constituting a transition period in the progressive improvement of the pasture. Over a considerable area of Australia, however, it appears improbable that top-dressing will ever be economically feasible. In Queensland, thanks to the work of Mr. J. C. Brunnich, of the Queensland Department of Agriculture, the practice has become practically universal in the central districts of administering licks to sheep compounded of salt and ground rock phosphate. The benefit accruing from these licks is undoubted. It is, I think, a fair estimate to say that the carrying capacity of certain districts has been increased 50 per cent. by this procedure. The bones of the sheep which used formerly to break when the sheep were sheared or otherwise handled, now resist fracture under reasonable conditions of handling. A striking result of the use of the lick is indicated by the observation of Mr. A. J. N. Gillespie, of "Orion Downs," who reports that on stations employing the phosphate lick, *Oesophogostomiasis*, which is a worm infection of the wall of the intestine, is absent, while neighbouring stations not administering this lick to their sheep are heavily infested. Apparently, the phosphate administration enables the sheep to resist invasion by this parasite, or else the phosphate itself renders the intestine uninhabitable by it.

It still remains to be ascertained, however, whether the lick thus administered is the most satisfactory that can be devised, Examination of the bones, of which we have a numerous collection, shows that they are not yet normal, and indeed the amount of phosphate consumed by the sheep is not sufficient to supply more than a fraction of their total needs. Either on the grounds of lack of palatability, or on the grounds of deficient assimilation, the lick as at present compounded does not remedy in full the prevailing deficiency.

We have, therefore, thought it advisable to undertake experiments upon licks containing a greater variety of phosphoric acid compounds. For example, besides phosphate rock, bone meal, dicalcic phosphate, which has recently become available upon the Australian market, neutralized super, which is dicalcic phosphate contaminated with gypsum, are preparations at present available, the relative efficacy of which in licks is not yet known. In addition to these it appears desirable, from what we now know of the physical chemistry of bone formation, to investigate the value of certain organic compounds of phosphoric acid. The one which suggests itself first as likely to be of use is calcium glycerophosphate. This salt has the enormous advantage over tricalcic and dicalcic phosphates that it is soluble in the intestinal contents at an alkaline reaction, whereas tricalcic and dicalcic phosphates are precipitated, and, therefore, to a considerable extent, are eliminated unabsorbed.

Calcium glycerophosphate has been employed in America for dairy cattle and pigs, and results have been obtained which indicate that it has superior qualities for promoting bone formation. Nevertheless, the experiments are not yet conclusive, because they have never been carried out in the presence of an excess of lime, which always renders assimilation of phosphoric acid more difficult. If iron should also be present, the assimilation of phosphoric acid will be rendered still more difficult, and it may be said that no more deleterious conditions could be encountered from the point of view of bone formation than the presence in the soil of a deficient amount of phosphoric acid together with an excess of lime and iron.

This is the condition which prevails in the area set aside for us at "Dismal Swamp," and this locality, therefore, presents a favorable set of conditions for testing the comparative value of licks under the most trying circumstances, but in deciding upon the situation upon which these experiments should be carried out, we were influenced by more important considerations still, namely, that as we would wish to analyse the sheep from time to time, and the analyses would necessitate their being slaughtered at the laboratory, the field-station for the testing of the comparative value of these licks could not be situated more than twelve hours' distance from the laboratory by rail. This pointed to the south-eastern district of South Australia, but it will be understood that these experiments are being carried out, not so much in the hope of benefiting the south-east of South Australia where the greater part of the land is so valuable that it pays handsomely to top-dress it, but in the interests of a much greater area of Australia in which phosphoric acid deficiency prevails in soil which, under present conditions, could not possibly be treated with top-dressing. There are areas in the south-east of South Australia, however, which fall into this category, and they, in common with Central Queensland and the other areas mentioned above, will benefit from any facts which we may ascertain at "Dismal Swamp." The owner, Mr. A. F. Sutton, has already top-dressed the greater part of his property, but he naturally applied the superphosphate, in the first instance, to his best land, proceeding to land of less value from year to year. He had 1,200 acres left upon his property to which no treatment had been applied, and it is this land which he has so generously placed at our disposal.

It represents an area of apparently severe phosphoric acid deficiency, intersected with outcrops of limestone and ferruginous rocks. It is our intention upon this property to follow the growth, general welfare, and wool production of eight batches of 25 ewe lambs each, subjected to the following conditions :—

(1) Pastured upon unimproved pasture, the only lick supplied being crude ocean salt.

According to Mr. Sutton, these lambs will thrive very poorly. We will, of course, not permit them to die, but when it is clear to us that their condition is seriously declining we will return them to the owner.

(2) Upon heavily top-dressed land. We are utilizing a portion of Mr. Sutton's property adjacent to the 1,200 acres which he has placed at our disposal. It was top-dressed two years ago with 1 cwt. super to the acre. We have supplemented this original top-dressing by an additional top-dressing of 2 cwt. of super to the acre.

(3) Ground rock phosphate (tricalcic phosphate).

(4) Bone meal.

(5) Dicalcic phosphate.

(6) Neutralized super, equivalent to dicalcic phosphate contaminated with gypsum.

(7) Calcium glycerophosphate.

(8) Calcium glycerophosphate with an equivalent amount of carbonate of lime, sufficient to render the proportion of lime to phosphoric acid that which is present in dicalcic phosphate.

All of these licks are so compounded with salt as to bring them to a common level of phosphoric acid content, with the exception of two (neutralized super. and calcium glycerophosphate plus carbonate of lime) which are diluted to a lower value of phosphoric acid content, equal, however, to each other. The whole experiment is so designed that we can compare equal phosphoric acid intakes from different sources of phosphoric acid, or, on the other hand, can eliminate the factor of unequal salt intake by comparing the efficacy of the two licks containing equal quantities of salt and unequal quantities of phosphoric acid.

The available area has been cut up into twelve paddocks, of which eight will be occupied at any given time, and four will always be resting. A system of rotation has been devised such that each group in its turn will have periodical access to fresh pasture. The carrying capacity to the acre is so low, however (half a sheep to the acre), that the area of the paddocks is considerable, and much ingenuity also was necessary in devising fences to avoid swamp areas and so forth which would have been a source of danger to the sheep, while keeping the paddocks of uniform quality and size. All this has involved considerable expense, and this field-station, with its eight separate groups of animals to compare, represents the maximum expenditure which I think we need anticipate upon any field-station. It will also represent a maximum amount of work for the field officer in charge. As we intend to make the investigation as extensive as possible, following not only the growth and welfare of the animals, but also the composition of their tissues, the distribution of phosphoric acid in them, the total amount of phosphoric acid assimilated, the phosphoric acid concentration in the blood, the hydrogen ion concentration in the stomach, the eruption and development of the teeth, and the composition and breaking strength of bones, we think that when the information is assembled it will be well worth the expense. It may turn out, of course, that ground rock phosphate is as good a source of phosphoric acid as any of those which we will investigate, but if a better source of phosphoric acid should be found, our results would undoubtedly be applicable to other phosphoric acid deficient areas, and should indeed prove of great value to Queensland, New South Wales, Western Australia, and Tasmania.

The chief drawback in the past to the use of glycerophosphates for nutrition has been their expense. Some fifteen years ago, however, I was engaged in work upon glycerophosphates, and came to the conclusion at that time that if there was sufficient demand for these compounds they could be synthesized comparatively cheaply. With this in mind, I placed my old notes at the disposal of Mr. Marston, and asked him to investigate the possibility that glycerophosphoric acid might be prepared directly from phosphate rock by treating it with the ordinary process employed for preparing super with sulphuric acid, using, however, 50 per cent. more sulphuric acid to set the phosphoric acid completely free and acting upon the phosphate rock in the presence of sufficient glycerine to transfer the whole of the phosphoric acid into glycerophosphoric acid. The experiment was attended with a gratifying measure of success, and we found that under these conditions, over 70 per cent. of glycerophosphate of lime is readily precipitated from the mixture by neutralization with carbonate of lime. The discovery of this process brings the commerical manufacture of glycerophosphoric acid within the economic range. In consultation with the Executive, we have decided that it would be best to patent this process, assigning the patent to the Commonwealth Council for Scientific and Industrial Research, so that there will be no opportunity for any manufacturer to anticipate us in patenting it before we have had the chance of publishing the process.

We have thought it important in connexion with these experiments to make careful observations of the eruption and development of teeth in each group of lambs. The front teeth of sheep are commonly observed by pastoralists, being used as an indication of the age of the animal, but in the opinion of dental authorities the eruption and cusp formation of the molar teeth afford a truer picture of arrested or abnormal developments of the teeth. We have been fortunate to secure the co-operation of Dr. Arthur Chapman, D.D.S., who has spent a considerable amount of time experimenting upon means of securing casts of the teeth of our lambs at the Waite Insitiute. Dr. Chapman and Mr. Lines have succeeded in devising a suitable technique for this purpose, and our field officer at "Dismal Swamp" has been instructed in its employment. It is our intention to take casts every fortnight of the teeth of four or five lambs in each of the eight groups of animals comprising the experiment. A comparison of the series of casts obtained from each group should, in the opinion of Dr. Chapman, afford a very striking picture of the progress of dentition in these animals. Dr. Chapman will himself probably visit the station once or twice to undertake additional observations of a technical dental character. The object of this investigation is not so much to ascertain whether defective phosphoric acid assimilation has a deleterious effect upon teeth, although that is the point of view from which Dr. Chapman naturally looks at the problem. From the point of view of the pastoralists, we are primarily interested in the question whether the development of teeth may be utilized as a means of diagnosis of phosphoric acid deficiency in the diet. It would, obviously, be more convenient to be able to tell at a glance or after taking a cast of the teeth that the animals are suffering lack of phosphoric acid than to resort to lengthy chemical examinations of the soil or herbage, or even determinations of phosphoric acid in the blood or tissues of the animals themselves. It is conceivable that with the information thus collected one might be able to decide in a very few minutes, in a district new to us and unknown as to the composition of its soils, that phosphoric acid was, or was not, deficient in the diet of the animals. The aid afforded by such a diagnostic sign, both to experimental investigation and practical husbandry of the sheep, would obviously be very considerable.

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COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

THE

MINERAL CONTENT OF PASTURES

PROGRESS REPORT
on
Co-operative Investigations at the Waite Agricultural Research Institute

MELBOURNE, 1930

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CONTENTS.

The Mineral Content of Pastures.

Progress Report on Co operative Investigations at the Waite Agricultural Research Institute.*

I. INTRODUCTION.

Importance of Mineral Deficiency Work on Pastures.

The majority of the sheep and cattle of the Empire are maintained entirely on natural pastures. Any improvement in the stock-carrying capacity, either of the natural or cultivated pastures of the Home country, or of the Dominions, would affect the material wealth of the Empire. The problems associated with pasture improvement are, however, of special importance to Australia, South Africa, and New Zealand.

Comparatively little work has been done on the nutritive value and composition of natural or seeded pastures, but facts of great importance in connexion with the influence of mineral constituents in grass lands have recently been brought to light. Over widespread areas within the Empire the occurrence of malnutrition of stock is common. In some cases, the pathological conditions are of a specific type and occur in well-defined regions. Thus Theiler and his associates (*Journal of the Department of Agriculture, South Africa*, 1924, p. 460), in South Africa, have shown that styfsiekte in cattle is caused by a phosphorus deficiency in the soil and in the vegetation. They have also found that the veld soils on which this phenomenon occurs are very low in phosphorus, and that on consequence the level of phosphorus in the vegetation is below the physiological optimum requirements of the cattle.

Bush sickness, a condition characterized by anaemia and emaciation, is found in the North Island of New Zealand, and the cause of the malnutrition is stated by Aston (*Transactions of the New Zealand Institute*, **55**, p. 720) to be due to deficiency of iron. Davis (*Journal of Agriculture, India*, **22**, p. 77) has drawn attention to the very low milk yield of cattle in the Bihar district of India, and has correlated it with a low percentage of phosphorus in the crops and soils of the State. Munro (Report on Falkland Islands, 1924) has drawn attention to the high mortality amongst sheep in the Falkland Islands, and Godden (*Journal of Agricultural Science*, **16,** 1926) has shown that the pastures of the Falkland Islands are very low in both lime and phosphorus as compared with the average cultivated pastures of England.

Similar cases of malnutrition have been recorded in the south of Scotland by McGowan (*Scottish Journal of Agriculture*, **5,** 1922, p. 274), and in Australia by Henry (New South Wales Department of Agriculture, Science Bulletin 12).

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* Manuscript received 31st August, 1929.

The general symptoms reported as occurring in parts of the Dominions and Colonies are the slow rate of growth, high mortality, low milk yield in cows, and low birth-rate. In most of the cases the animals suffer from an abnormal craving for certain inorganic substances. A number of causes contribute to these various nutritional troubles. In many cases, however, it seems certain that the chief cause of malnutrition is a deficiency of essential mineral elements in the pasture. Chemical analyses show that the soils and pastures in the areas where malnutrition occurs have an abnormally low content of one or more of these elements, and that by supplying these deficient minerals in the diet, a marked improvement in the rate of growth of the animals has resulted.

Important investigations have been conducted at the Rowett Institute, Aberdeen, and these have shown that, while there is no striking difference in the energy value between good and poor pastures, there are wide variations in the proportions in which the mineral constituents are present in rich and poor pastures.

It has also been shown that the differences in the mineral content of pastures correspond closely with the value of the pasture, a high mineral content being associated with a high nutritive value. The demonstration that the mineral constituents of the pasture is of an importance at least equal to the energy-yielding constituents, opens up possibilities of a very far-reaching kind, both economic and scientific.

The problem of pasture improvement is of special importance to Australia, South Africa, and New Zealand, not only because of the almost absolute dependence of the animal industries on the pasturage of the country, but also because over large areas of each Dominion the soils are actually deficient in various mineral nutrients, particularly soluble phosphates. These deficiencies are reflected in the composition of the pasture, and markedly influence the health of the animals grazing on the mineral deficient pasture.

II. ORIGIN OF INVESTIGATIONS.

It was suggested by Professor A. E. V. Richardson, after a visit to the Rowett Institute in 1926, that the general question of mineral deficiency in the soils and pastures was a phenomenon of Empire interest, affecting the welfare of the live-stock of both Great Britain and the Dominions, and that the study of these mineral deficiencies on the composition and grazing value of the pasture and on the nutrition of the animal might well be made the subject of co-operative investigation in various parts of the Empire.

In 1927 the Empire Marketing Board agreed to undertake, in co-operation with the Council for Scientific and Industrial Research and the University of Adelaide, an investigation into the mineral content of pastures in Australia. The Board agreed to provide £3,000 towards the cost of erection of a laboratory and an annual maintenance grant of £1,875 for five years.

The Council for Scientific and Industrial Research agreed to provide a sum of £3,000 towards the cost of a laboratory for the investigation of the mineral content of pastures and the soils problems associated with the Murray settlements, and a sum of £937 10s. for five years towards the maintenance cost of the mineral deficiency investigations. The University also undertook to provide a sum of £3,000 towards the cost of the laboratory, and £937 10s. per annum for five years towards the cost of the investigation.

Through the generosity of Sir John Melrose, of Ulooloo, who in 1927 gave £10,000 to the University for the building of laboratories at the Waite Institute, the first block of permanent laboratories was built. The foundation stone of the new building was laid on 26th January, 1928, and the building officially opened by His Excellency the Governor of South Australia on 22nd April, 1929. The total cost of these laboratories, exclusive of apparatus and scientific equipment and roadways, was £19,300.

The cost of the mineral deficiency investigations is borne by the three contracting parties, and appropriations are paid into a "Mineral Deficiency of Pastures Fund," administered by the University of Adelaide. Audited financial statements are submitted at half-yearly intervals to the three parties concerned.

At the outset of the investigation, the Empire Marketing Board suggested that it would be an advantage to the investigation if certain of the workers (e.g., the chemist, the agronomist, and the field-worker, &c.) from Australia should spend a preliminary period at Institutions in Great Britain which are co-operating in this investigation.

In view of the shortage of trained men in Australia, it was considered that the principle involved in the Empire Marketing Board suggestion might be carried out by appointing a biochemist (Mr. A. H. Sim, B.Sc., B.Ag.Sc.), specially trained in pasture work, from the Rowett Institute at Aberdeen, and a trained agrostologist (Dr. J. G. Davies) from the Welsh Plant Breeding Station. At the same time, the agronomist of the Waite Institute (Mr. H. C. Trumble, M.Agr.Sc.) spent a period of twelve months abroad, mainly at the Rowett Institute and the Welsh Plant Breeding Station, in securing experience at these Institutes.

The investigations were commenced in July, 1927, but owing to lack of laboratory facilities in the earlier stages it was not possible to appoint the full staff contemplated under the agreement until early in 1929, when the permanent laboratories became available. The full-time staff engaged in this investigation now consists of three chemists, two agrostologists, one agronomist, and two botanical assistants.

III. SCOPE OF THE INVESTIGATIONS.

The object of the work, in general terms, is to investigate the mineral content of pastures with a view to determining the grassland areas in which deficiencies exist, and the most economic methods of correcting such deficiencies.

The natural grassland associations found in any locality or on any given area are a reflex of the environment—expressed in terms of climate, soil composition, and pasture management—under which the pasture type is grown. These grassland associations in any given climatic region may be profoundly altered in botanical and chemical composition and in nutrient value, by the use of fertilizers, by the introduction of new pasture plants into the sward, and by varying the character of the pasture management. Hence an important phase of the study of the mineral content of pastures is the classification of the more important grassland associations, and the demonstration of the relationship between the composition of the pasture and the soil on which it is found. Indeed, the classification of grasslands according to the natural pasture associations is fundamental to work bearing on grassland improvement. Moreover, the individual species constituting the principal pasture types must be known thoroughly from the physiological and chemical aspects, and the biological phenomena causing change or successional development in grassland associations must be thoroughly understood if grassland improvement is to rest on a scientific basis.

Not less important in connexion with the special problem of the mineral composition of pastures is the investigation, under controlled conditions, of the precise influence of (i) species; (ii) stage of growth; (iii) rate of growth; (iv) soil type; (v) soil fertilization; and (vi) soil moisture content, on the mineral content of typical pastures.

By reason of the special significance of rainfall to pasture production in the semi-arid regions of the Empire, the intake of mineral nutrients in relationship to transpiration needs investigation.

In view of the principles enunciated above, it was felt that the problem of mineral content of pastures must be investigated from a much broader viewpoint than was originally contemplated; hence the ecological and agrostological aspects of the problem have been emphasized as well as the purely chemical aspect.

As very little scientific work has hitherto been carried out on the indigenous pastures of Australia, much attention has been given to the working out of a technique adapted to the investigation of indigenous grasslands. Satisfactory methods have been developed to measure the productivity, grazing value, botanical composition, and ecological succession of indigenous pastures.

IV. INVESTIGATIONS IN PROGRESS.

(1) Laboratory and Pot-Culture Investigations.

(i) Factors affecting the Mineral Content of Pastures.

Much attention has been devoted in the early stages of the investigation to the determination of the precise effect of various factors which may influence the mineral composition of plants. Such a study was regarded as fundamental to any extensive work in the field.

The investigation took the form of determining the effect on mineral composition of typical pasture plants of the following factors (i) stage of growth; (ii) soluble phosphates; (iii) soil type; (iv) moisture content of the soil; (v) rate of growth as affected by soil temperature.

As rainfall is a limiting factor to pasture production over a large portion of Australia, the relationship of the absorption of mineral nutrients to transpiration was determined in all cases. In these investigations, the pasture plants were grown under controlled conditions in glazed earthenware pots of 20-litre capacity, and records of transpiration were obtained at weekly intervals throughout the investigation.

(a) *Effect of the Stage of Growth.*

Considerable attention has been devoted to the study of the effect of the stage of growth on the mineral nutrient content of pasture plants, because virtually the whole object of efficient pasture management rests upon the maintenance of herbage in that condition of growth in which the mineral content is a maximum.

Five varieties of plants have been critically examined with regard to the influence of growth stage on mineral composition. Barley has been chosen as a typical gramineous annual, *Trifolium subterraneum* as a typical clover, *Danthonia penicillata* as a representative permanent indigenous grass, *Erodium botrys* as a common herbaceous constituent in semi-arid pastures, and *Lolium subulatum* as a typical exotic grass.

The stage of growth of the plant determines the protein and mineral composition of the herbage. Thus a *Lolium subulatum* pasture at the tillering stage contained 5.2 per cent. of nitrogen, equivalent to over 31 per cent. of crude protein, whilst in mature herbage the percentage fell to 1.04 per cent. of nitrogen or 6.5 per cent. of crude protein. Similarly, the phosphate content (P_2O_5) of the herbage fell from 1.44 per cent. at the tillering stage to 0.36 per cent. at maturity.

With each of the five groups of plants examined the absorption of mineral matter and nitrogen was extraordinarily rapid in relation to the amount of water transpired and dry matter synthesised from tillering to flowering. Thus with gramineous plants 86 per cent. of the total nitrogen, 82 per cent. of the potash, and 60 per cent. of the phosphoric acid had been absorbed before 40 per cent. of the total dry matter had been synthesised, and before 34 per cent. of the total water used had been transpired.

It was found that the transpiration ratio of pasture plants varied considerably with the stage of growth. Grasses and clovers, for example, produced dry matter at a relativley low water cost during the early stages, but in the final stages, the cost of dry matter produced was relatively high. This result, taken in conjunction with the high protein and mineral content of young grass, is of great economic significance in pasture management in semi-arid regions—where rainfall is a controlling factor in pasture productivity.

(b) *Effect of Phosphates.*

The importance of phosphorus as a factor limiting the production of grass and live-stock in Australia, and the large area of phosphate deficient soil justify close consideration of the influence of soluble phosphates on the mineral composition of the pasture.

The effect of soluble phosphates on the transpiration ratio of pasture plants has also been investigated. The results show that the application of soluble phosphate produced a substantial increase in the phosphorus content of pasture plants and led to a marked reduction in the transpiration ratio. The most pronounced effects were observed during the early stages of the plant's growth, where increases in the phosphorus content of from 50 per cent. to 80 per cent. were frequently obtained. But even at maturity it was found that the phosphorus content of all pasture plants except *Danthonia*, a native perennial species, was increased from 33 per cent. to 40 per cent. by applying soluble phosphate to the soil. Species of *Danthonia*, an indigenous grass with widespread distribution in Australia, were found to be less responsive to soluble phosphates than other pasture plants examined. In all cases, however, the application of soluble phosphates produced a marked reduction in the transpiration ratio, particularly in the early stages. With *Danthonia* this reduction varied from 9.4 per cent. to 16 per cent., according to the stage of growth. With *Lolium* the range was from 12 per cent. to 18 per cent. reduction; whilst with *Erodium botrys*, an introduced annual, the lowering in transpiration ratio by the use of phosphates exceeded 30 per cent. These results are of economic significance for pasture production in regions of light rainfall.

(c) *Influence of Soil Type.*

The chemical composition of the soil has an important influence on the composition of the plant. To obtain precise information on the effect of soil type on the mineral content of pasture plants, a range of soils of known agricultural capacity were selected and brought in bulk to the Waite Institute. The types selected ranged from soils known to be markedly deficient in phosphate, and to types unresponsive to applications of phosphate. *Trifolium subterraneum* and *Lolium subulatum* were grown in each soil type, without fertilizer and with a liberal application of soluble phosphate, to determine the variations in composition of each species grown on the different soil types, and the extent to which phosphatic fertilizers can affect the phosphate content of pure species on phosphate rich and phosphate deficient soils. This investigation has not yet been completed.

(d) *The Influence of Rate of Growth.*

There are two widely dissimilar grassland regions in Australia—the Northern tropical area, where young herbage growth is rapid because of the high soil and air temperatures during the growing season, and the Southern winter grassland region, in which early pasture growth is slow because the rainy season synchronises with low temperatures. It is possible that the rate of absorption of mineral nutrients may be greatly influenced by soil and air temperatures which affect the growth rate as measured by the rate of production of dry matter. Preliminary investigations have been commenced to determine the influence of the soil temperature factor on the mineral absorption and growth rate. Barley has been taken as a plant typical of the annual grasses. Six water tanks, each of a capacity sufficient to maintain eight pots, have been used for the purposes of this investigation, and these have been maintained throughout the present growing season (1929) at temperatures of 10°, 15°, 20°, 25°, 30°, and 35° C. The plants will be harvested at a uniform growth stage, e.g., appearance of first flowering stalk, and determined for relative mineral absorption, dry matter increase, and transpiration per unit of mineral matter and dry matter produced.

(e) *Effect of Soil Moisture Content.*

In view of the extensive areas of land in the Empire with low rainfall, the effect of drought on the chemical composition of the pastures needs investigation. From comparisons of the composition of cereals grown in wet and dry seasons it would appear that mineral absorption, particularly phosphate intake, is lowered during periods of drought. To obtain definite information on this point a series of 120 pots of 20-litre capacity were planted with *Lolium subulatum* in May, 1929. Half of these were fertilized with soluble phosphates and half were unmanured. The pots were maintained at a moisture content of 50 per cent. water holding capacity until tillering was active. A harvest was taken at this stage from 27 of the pots. The remainder were then divided into three groups,—(*a*) one series maintained at 30 per cent. water-holding capacity, (*b*) one series maintained at 55 per cent. saturation, (*c*) one series maintained at 80 per cent. saturation. These pots will be harvested at flowering and at maturity, and the material analysed for phosphate and mineral content at each stage of growth.

(ii) Survey of the Composition of Pasture Plants from Mineral Deficient Areas for Detailed Mineral Analysis.

Pasture material is being collected as opportunity offers from various parts of Australia where mineral deficiencies are alleged to exist. In course of time, these analyses will show the range of variation in the mineral composition of given species of pasture plants grown under widely dissimilar climatic and soil regions throughout Australia. To interpret such analyses properly, however, it is very necessary to know the composition of a wide range of pasture species grown in a known or controlled environment. It is also essential to compare the pasture plants at fixed stages in their vegetative growth, because of the known variability in mineral and protein composition as growth advances to maturity. The extent to which the normal composition of a plant can be modified by rainfall (as expressed in terms of average moisture content of the soil), fertilizers, &c., must be known.

A large number of species commonly used in seeded and natural pastures have been grown under uniform conditions at the Waite

Institute, and harvested at a fixed growth stage, e.g., exsertion of anthers, for detailed analyses. Pasture species have been collected from mineral deficient areas on the Eyre Peninsula, Yorke's Peninsula, and the South-eastern District of South Australia, and analysed for mineral content. The relationship of the composition of the pasture type to the composition of the soil on which it is grown will be investigated.

(2) Field Investigations.

(1) The Effect of Varying Intensities of Grazing on the Yield, Botanical and Chemical Composition of Indigenous Pastures.

Depletion of the pasture resources of the Commonwealth has been attributed to overstocking of the pasture by graziers. To ascertain the effects of varying intensities of grazing on the indigenous pasture, an investigation was commenced in 1927 and continued in 1928. The area selected was a typical natural pasture in the Adelaide district (average rainfall 23 inches). The pasture was top-dressed at the rate of 1 cwt. per acre in 1925 and in 1926, but during the progress of this investigation no fertilizers were used. Plots of 1 square metre in area were used, ten replications of five treatments being arranged in two blocks of five replications. The treatments within each block were randomly distributed on the Latin square system. The following five treatments were employed :—

1. Pasture cut at fortnightly intervals during the growing season.
2. Pasture cut at intervals of four weeks.
3. Pasture cut at intervals of seven weeks.
4. Pasture cut at intervals of ten weeks.
5. Pasture cut at the conclusion of the growing season.

No system of artificial cutting has precisely the same effects on the pasture as the grazing animal. Sheep, for example, graze selectively. The shears or mowing machine has also a selective action, but of a different nature. Sheep graze species that are palatable, whereas the shears cut more or less drastically those species that have an erect habit of growth, the prostrate and rosette species not being injured to the same extent.

Each plot was harvested separately, the herbage botanically analysed, dried to constant weight, and the yield of dried herbage obtained from each series. For chemical analysis, the ten replications from each plot were grouped and representative samples obtained. The results of this investigation, extending over two seasons, will be available for publication shortly. Meantime, the general results may be briefly mentioned.

The greatest yield of dry matter per acre was obtained in Series 5—in which the pastures were cut at completion of growth. The lowest yield of herbage was given under Series 1—cutting fortnightly, which corresponds with practically continuous grazing. The highest percentage of protein and minerals in herbage was obtained under fortnightly cuttings.

The most marked features of the botanical analysis were the reduction in the proportion of leguminous herbage under intensive cutting, and of the permanent grass in the association, *Danthonia penicillata*, and a relatively large increase in species with rosette habit of growth, e.g., *Erodium botrys*.

On Series 3, however—corresponding to cutting at intervals of seven weeks—the maximum yield of minerals and protein was obtained per acre. The total yield of grass on this series of plots was actually 91½ per cent. of the weight obtained on plots where the grass was allowed to grow to completion, but the herbage had a much higher protein and mineral content and much less fibre than the plots on which the herbage was cut at completion.

From the results of this investigation, it would appear that on indigenous pastures grown under winter rainfall conditions, three cuttings at intervals of seven weeks gives a higher yield of minerals and nutrient matter per acre than any of the other forms of pasture cutting employed, and at the same time a good balance between the leguminous and non-leguminous components of the pasture is maintained.

(2) Investigation of the Effect of Applying Soluble Phosphate to Natural Pastures, and of the Value of Phosphatic Licks Fed to Sheep when Grazing on Unmanured Pasture.

The importance of phosphorus as a factor limiting the production of both grass and live-stock in Australia fully justifies an exhaustive investigation of the mechanism by which soluble phosphate influences the output of natural pastures.

For the purpose of such an investigation, 50 acres of natural pasture at the Waite Institute have been subdivided into ten blocks of 5 acres. The land is uniform in quality and has been grazed continuously with stock for upwards of 40 years.

In 1928, the area was fenced and tested for uniformity in yield and sheep-carrying capacity. Intensive investigations were made during the running of this blank experiment in 1928 to evolve a technique for obtaining reliable data on the yield, and the botanical and chemical composition of the pasture. In May, 1929, four of the ten blocks of 5 acres were top-dressed with superphosphate at the rate of 2 cwt. per acre. Four blocks remain untreated for purposes of control plots; two blocks are used for grazing sheep which have access to an unlimited quantity of phosphatic lick. Data will be obtained of the effect of each treatment on—

(1) The growth, development, and yield of indigenous pasture.

(2) The mineral and nutrient composition of the pasture.

(3) The botanical composition and successional development of the pasture.

(4) The growth, development, and live-weight increase of sheep, and the yield and quality of the wool.

To obtain a uniform stock for the experiment, 300 merino wether weaners were purchased from a line of 7,000 sheep from the Mutooroo Pastoral Company, and of these, 62 sheep were selected for size, weight, conformity to type, and uniformity in wool characters. It is proposed to maintain each group of sheep on their respective blocks and treatments for a period of three years.

The number of sheep carried has to be judged from previous experimental knowledge and from the results of the "blank" trial in 1928. The following numbers are at present used:—Top-dressed plots, 32 sheep; unmanured plots, 20 sheep; lick plots, 10 sheep. In order that lack of herbage will not be a limiting factor to growth on any block, the plots are being deliberately understocked during the first year. Each lot of sheep is grazed in rotation on a pair of blocks, and the individual sheep are weighed at the conclusion of each week's grazing.

The quantity of lick consumed by the sheep on the phosphate lick blocks is measured at weekly intervals. At shearing the yield of wool from each lot of sheep will be recorded, together with the grading of its quality.

For the purposes of estimating the yield of pasture, ten plots each 10 x 5 links in area are cut on each of the ten grazing blocks each month during the growing season. These areas are protected from grazing by wooden hurdles around each plot. In addition, ten plots are cut on the grazed portion of the blocks. In this manner the amount of herbage consumed by the sheep each month may be determined by the difference in weight of oven-dried herbage between the protected and non-protected blocks. These pasture cuts are made at monthly intervals by a two-stand portable sheep-shearing machine, which has been specially adapted for pasture cutting. The herbage from each plot is botanically analysed into fractions which are weighed and analysed for mineral nutrients, fibre, and proximate constituents. At three periods each year a botanical analysis of the pasture *in situ* is made, using the percentage estimation method. This method of analysis yields information on the seasonal change in the character and composition, together with the effect of the three treatments on successional change in the pasture. At the same time, data on the palatability of the species constituting the pasture is obtained by the method of analysis which has been developed.

The land on which the investigation is conducted is deficient in soluble phosphate, and should provide detailed information, not only of the precise effects of applying soluble phosphates, but also on the comparative advantages of supplying phosphates directly to the animal in the form of lick, and indirectly by applying it to the vegetation as artificial fertilizer.

(3) Effect of Various Phosphatic Fertilizers on the Productivity and Grazing Value of Indigenous Pasture.

The first grassland experiments at the Waite Institute were commenced in 1925, when a series of five plots, each an acre in extent, were laid down on typical indigenous natural pasture. The central plot received no manure, and the remaining four plots were top-dressed each year with equivalent amounts of phosphate (40 lb. P_2O_5 per acre) as (*a*) superphosphate, (*b*) superphosphate and nitrate of soda; (*c*) rock phosphate; (*d*) basic slag. The plots are separately fenced and have been individually grazed by sheep during the last three seasons. Three grazing periods of three to four weeks' duration are employed, and the sheep are weighed prior to, and at the conclusion of, each period. The plots are maintained in a closely-cropped condition without being over-grazed, and records of sheep days per plot are taken as an index to carrying capacity.

The system of three separate grazings is in close agreement with a system of three cuts which, from a series of cutting tests on natural pasture, has been shown to yield the highest productivity. Since the inception of the experiment, the nature of the pasture has considerably improved as a result of management alone.

Yields of the herbage produced on each plot are obtained from within a series of specially constructed quadrats consisting of frames of angle iron and wire-netting. Each covers $2\frac{1}{4}$ square metres of pasture, and the frames are placed approximately at 1 chain intervals on each plot. The enclosed areas of pasture are cut at the completion of each season's growth and the harvested material botanically and chemically analysed.

Over a period of four years, superphosphate and nitrate of soda have produced the highest average yield of dry matter, this being 169 per cent. of that from the control plot. Superphosphate alone produced 165 per cent., basic slag 156 per cent., and rock phosphate 112 per cent. respectively of the yield obtained with no manure. Marked changes were observed in the botanical composition of the pasture top-dressed with superphosphate and with basic slag—first annual clovers, then annual exotic grasses, and thirdly *Erodium botrys* dominating the association induced, whereas the dominant constituent of the unmanured plot has been *Danthonia penicillata* during each year.

In terms of sheep days, the application of superphosphate and also of superphosphate and nitrogen have more than doubled the stock-carrying capacity of the pasture.

Chemical analyses have shown that the soluble ash content of the pasture has approximately been doubled by top-dressing with superphosphate, increases being obtained in the percentages of lime, magnesia, phosphoric acid, soda, and potash. In the case of phosphoric acid, the percentage content was increased by 139 per cent.

Apart from the foregoing data, considerable experience of the pasture type and development of technique have been obtained, and the experiment also has indicated the importance of investigating, in detail, the mechanism of the effect of superphosphate on the development of both pasture and sheep, and this is being provided for by the experiment previously described (pp. 13–15). In addition, it has indicated that nitrogenous fertilizers under certain conditions may exert an appreciable influence on the productivity of indigenous pastures.

(4) Effect of Soluble Phosphates and Lime Applied to Natural Pasture on the Growth of Pasture, Live-weight Increase in Sheep, and the Yield and Quality of Wool in a Region Deficient in Lime and Phosphates (Kybybolite).

In May, 1929, an investigation was commenced in co-operation with the South Australian Department of Agriculture at the Kybybolite Experimental Farm to determine the effect of top-dressing with phosphates and lime on indigenous natural pasture deficient in these ingredients.

For the purpose of this investigation, the top-dressing experiments on indigenous pasture which were inaugurated by the Department of Agriculture in 1924 were used and, in addition, an area of 14 acres of natural pasture was made available to study *ab initio* the successional change in vegetation as a result of manuring. Ten 1-metre quadrats are used on each of three blocks of pasture—

(1) Unmanured,
(2) Top-dressed with superphosphate,
(3) Top-dressed with superphosphate and lime.

The herbage from protected and non-protected quadrats is cut three times during the growing season, botanically and chemically analysed, and after each cutting the location of the quadrats is changed. The live-weight increase of 40 Mutooroo weaner wethers, similar in age and quality to those used in the Waite Institute experiments, is recorded at monthly intervals.

Through the courtesy of the Department of Agriculture, 20 Mutooroo sheep of similar age and quality to those used in the Waite Institute and Kybybolite have been placed on natural pasture at the Booboorowie Experimental Farm, which is located in one of the best sheep districts in South Australia. Half of these are grazed on top-dressed pasture and half on non-top-dressed indigenous pasture. A comparison will thus be obtained of the growth of sheep of similar age, breed, and quality on unmanured and on top-dressed natural pasture at three markedly different grassland regions, namely, the rich grassland region of Booboorowie (Lower North), the phosphate deficient region of Adelaide, and the phosphate and lime deficient region of Kybybolite (South-east).

(5) Effect of Rotational Grazing and Intensive Manuring with Phosphates and Nitrogen on the Growth of Pasture on a Grassland Region of Heavy Rainfall (Mount Barker).

An experiment was started in May, 1929, on behalf of Imperial Chemical Industries on 25 acres of pasture land in the Mount Barker district (30 inches rainfall) to determine the effect of liberal manuring with phosphates and nitrogen on the milk yield of dairy cattle. Though the experiment is mainly directed to the determination of the value of nitrogenous and phosphatic fertilizers under intensive grazing conditions, the data that is being obtained on the successional change in the grassland as a result of manuring and rotational grazing will bear directly on the mineral deficiency investigation.

(6) Problems of Field Technique.

(a) *Determination of Experimental Error in Indigenous Grassland Tests.*

From experience obtained in the conduct of experiments on the yield of indigenous pasture, it was found that considerable error is attached to the estimates of yield obtained by using a replicated system of small plots. The extent of the error, however, was not known. In 1928 an experiment was designed to inquire into the magnitude of this error, and to ascertain by statistical methods the most desirable size of plot to use, together with the number of replications required to reduce this error within definite limits. One ½ acre of typical indigenous pasture was divided into 1,000 plots, each measuring 10 x 5 links, and each plot was harvested separately, using a two-stand portable shearing machine for cutting. The herbage was dried and weighed from each individual plot, and representative samples from 125 of the plots were hand separated, and the contribution of each species to the total yield of herbage on the plots was ascertained.

The data thus obtained is now being analysed and will show the size of the plot and number of replications necessary to reduce the error within definite limits, and whether a replicated system of plots, satisfactory from the stand-point of gross yield, will give an adequate representation of the botanical composition of the pasture. The results will be available later for publication.

(b) *Determination of Botanical Composition of Pasture by Mesh Analysis.*

For the determination of the factors that operate to produce change in the composition of pasture sward, a rapid method of estimating with reasonable accuracy the composition of a pasture sward is necessary. The cutting of large numbers of samples of the pasture, and the hand separation and weighing of the contributing species is a laborious procedure. A method of analysis has been worked out with a mesh of 4 square links for indigenous pasture which gives very rapidly and with considerable accuracy the percentage of land covered with vegetation, the species contributing to the pasture and the percentage contribution of each species. The method is of great value in studying the successional development of indigenous pastures under varying conditions of soil fertilization and pasture management, and in accurately classifying pasture associations.

(c) *Determination of Seasonal and Total Productivity of Indigenous Pasture on Land Rotationally Grazed with Sheep.*

Investigations are in progress to ascertain the best method of determining (*a*) the seasonal and total productivity of indigenous pasture under actual grazing conditions, and (*b*) the amount and botanical composition of herbage consumed by the sheep. The former is determined from the yields of herbage obtained from an adequate number of protected quadrats. The latter is determined by the difference in yield of herbage in closed quadrats as compared with yields from adjacent unprotected quadrats. After each grazing period the herbage from protected and non-protected quadrats is removed in a uniform manner by means of a sheep-shearing machine adapted for the close cutting of grass, and the botanical composition of herbage determined in the laboratory, and compared with the results of mesh analysis made on the pasture as a whole. After each cutting, the quadrats are redistributed over the grazed area. The number and size of quadrats required in relation to the area grazed is important, especially in assessing the significance of the yields, seasonal productivity, and the calculated amounts of herbage eaten by the sheep.

(*d*) *Relative Palatability of Species under Grazing Conditions.*

Some progress has been made in determining the comparative palatability of species, both on sown pastures and with indigenous pastures.

(7) The Pure Species Problem in relation to the Mineral Content of Pastures.

For the adequate growth of stock on pastures and their maintenance at a high level of production, certain necessary minerals and protein must be provided in adequate quantities over the entire grazing season. While the environment exerts an important influence on the mineral content of each plant species, there is a limit to the ability of plants to make use of available mineral nutrients, a limit imposed by the nature of the species itself. It is now known that plants grown under similar conditions do vary widely in mineral content. Clovers, for example, are generally richer in minerals, and particularly in calcium, than are grasses. Little, however, is known regarding the mineral content of pasture plants other than grasses and legumes, but Stapledon states (Ministry of Agriculture, Publication 60, pp. 57, 76) that both chicory and rape rank with red clover in possessing a mineral content definitely higher than that of grasses. Evans (*Welsh Journal of Agriculture*, Vol. III. (1927), pp. 119–147) has shown that *Molinia*, *Nardus*, and the sedge-like plants that compose "bog hay" are characteristically low in mineral content, and it is interesting to note that the Welsh upland cattle, notably small in body frame, are raised largely on Molinia pastures.

Kincaid (*Proc. Roy. Soc. Victoria*, Vol. XXIII., Pt. II. (1911), pp. 368–391) showed that the phosphate content of Australian native plants was definitely lower than that of exotics grown in the same soil.

Results at the Waite Institute indicate that *Danthonia penicillata*—the common perennial indigenous pasture grass of Southern Australia—is considerably lower in phosphate content and in minerals generally than Mediterranean plants grown and harvested under the same conditions. With this plant, moreover, liberal application of soluble phosphorus has not materially increased the phosphorus absorption with growth.

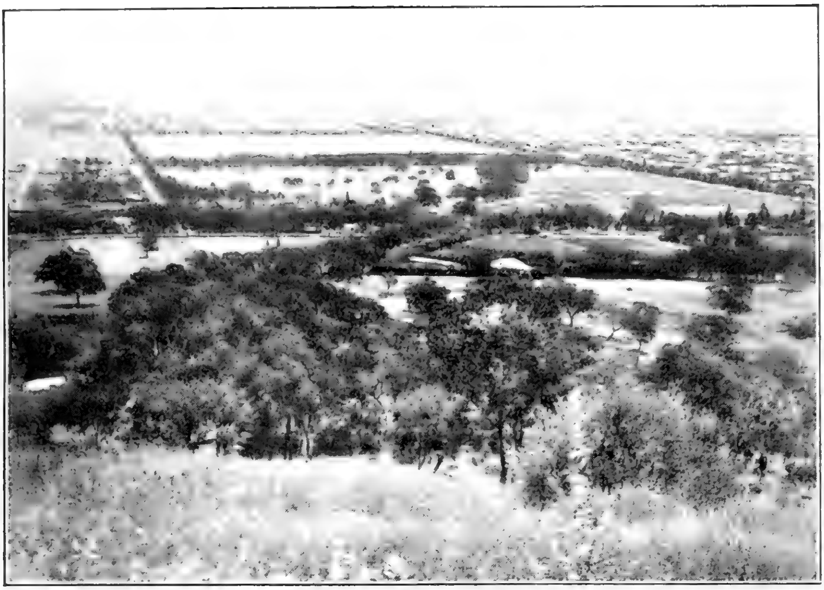
Investigations at the Waite Institute have also indicated that *Erodium botrys* (Geraniaceae) which in certain years may comprise 50 per cent. of top-dressed pasture, and which is an important pasture plant in many parts of Southern Australia, possesses a high capacity to take up mineral matter, and contains a high percentage of lime (over 3 per cent.).

Differential ability to absorb mineral nutrients from non-water-soluble sources in the soil is a further possibility among pasture plants. This phase is being investigated and preliminary experiments have been commenced in sand cultures with *Erodium botrys* and *Trifolium subterraneum*.

Pure species investigations in relation to the mineral deficiency problem are important because of the possibility of establishing, by proper management, a minerally balanced productive pasture. Some 200 pasture and fodder species have been established in a grass garden, and the more promising types are being tested under field conditions to determine their persistency, palatability, and general adaptability to a semi-arid environment.

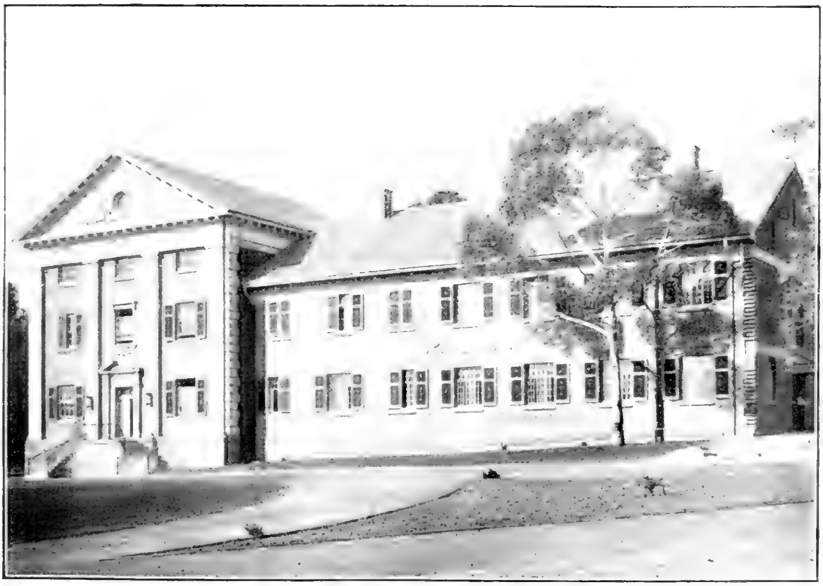
A. E. V. RICHARDSON.

27th August, 1929.



1. View of Waite Institute from Hills, taken in 1926.

Note pasture top-dressing tests cut for hay on left, experimental fields with ripening cereal plots on right, and large block now used for grazing tests in far distance. White dot marks site of permanent laboratories.



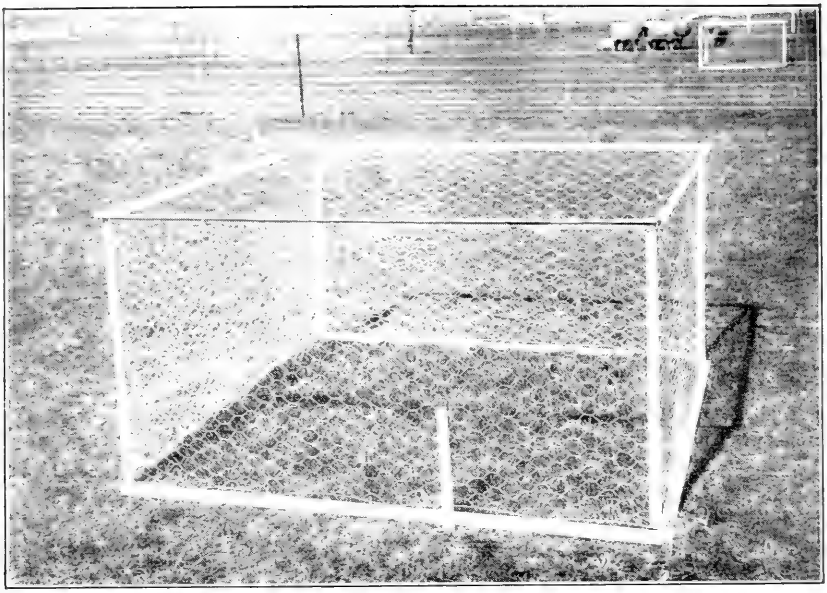
2. View of Permanent Laboratories Erected during 1928.
(John Melrose Laboratory opened on 22nd April, 1929.)

3. Interior of Glass House used for Water Requirement and Mineral Nutrition Investigations with Pasture Plants and Cereal Crops.

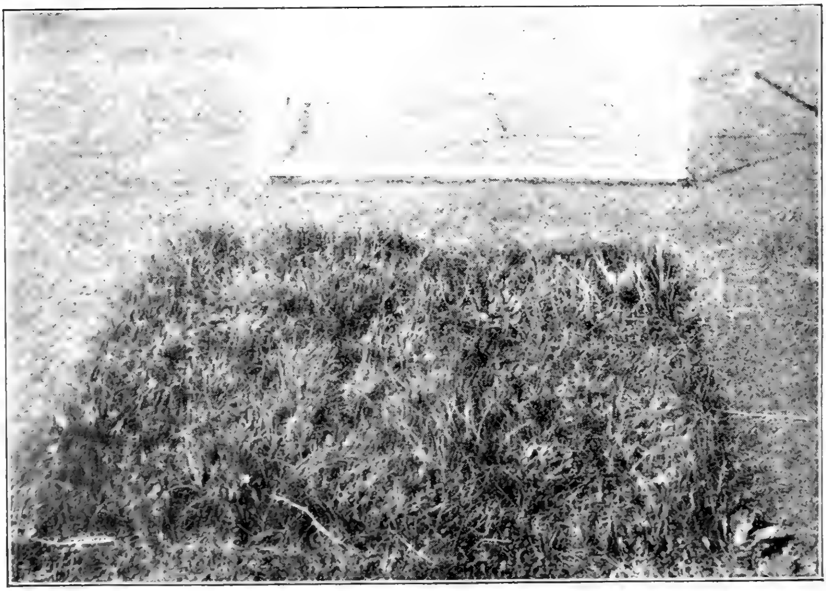
4. Pot Culture House from Outside showing Water Cultures (Inside House), Large Glazed Pots used for Water Requirement Investigations, and Small Unglazed Pots (Foreground) containing New Pasture Plants which are subsequently transferred to Grass Garden or Field.

5. View of Top-dressing Tests showing Sheep Grazing on Plots.

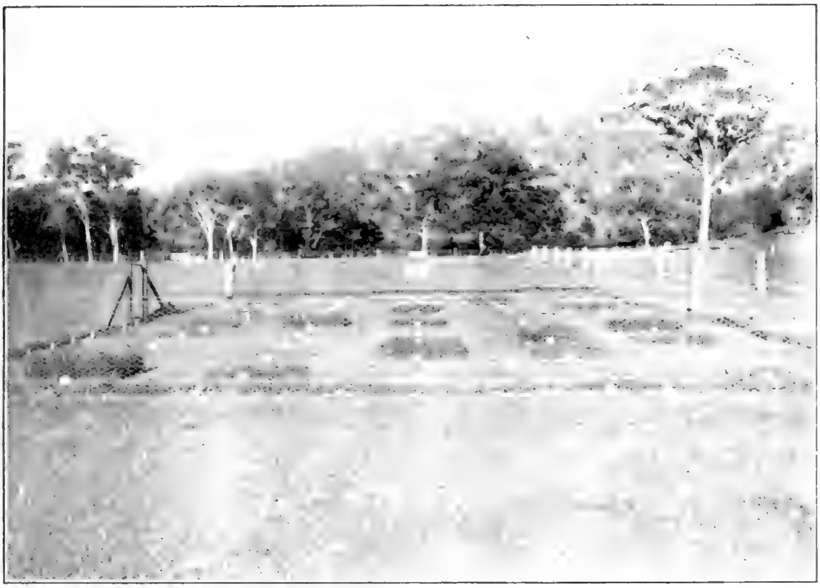
Note quadrat frames used to protect areas for cutting.



6. Quadrat Frame on Unmanured Plot with Ungrazed Herbage Protected from Sheep. The Surrounding Pasture has been Closely Grazed.

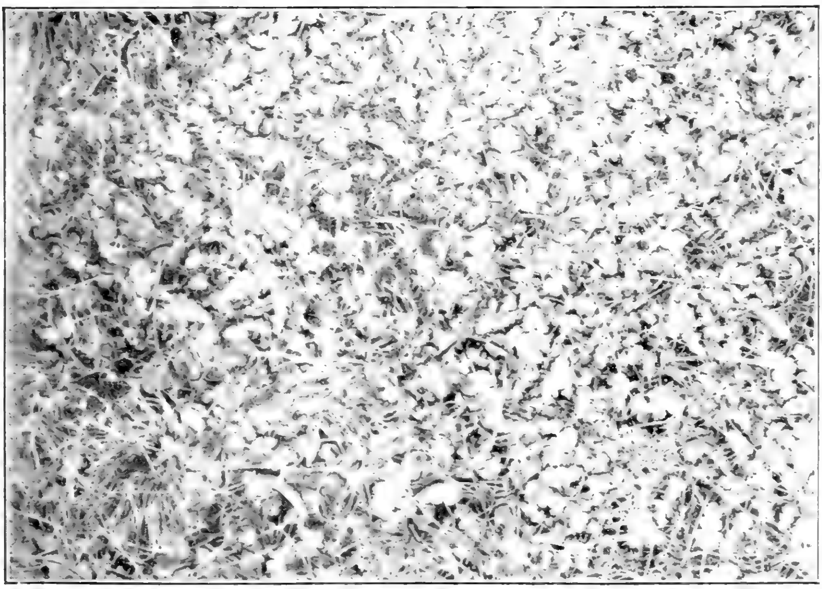


7. Quadrat Frame on Plot Top-dressed with Superphosphate Removed to show Ungrazed Herbage Growing within the Frame.



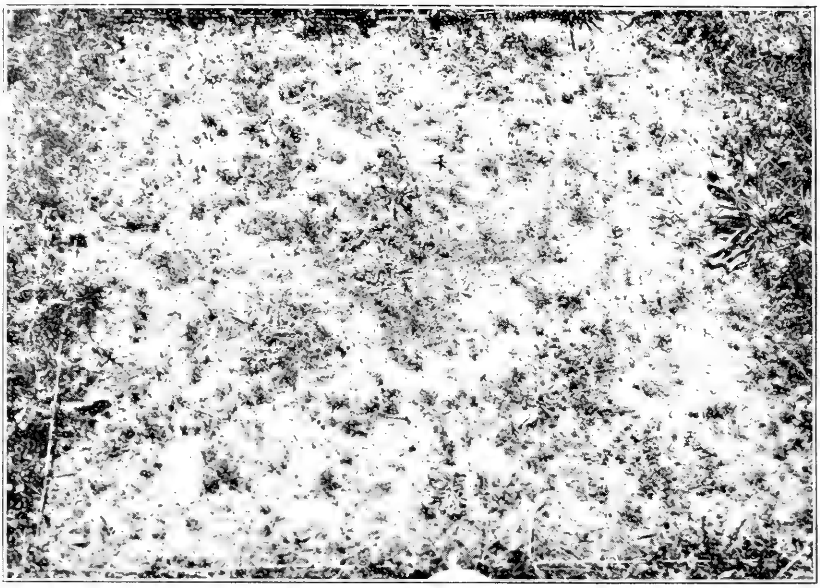
8. View of Pasture Cutting Tests October, 1927.

At this time 1s (cut fortnightly) had received 6 cuts, 2s (cut every four weeks) 3 cuts, 3s (cut every seven weeks) 2 cuts, 4s (cut every ten weeks) 1 cut; 5s cut at completion only.



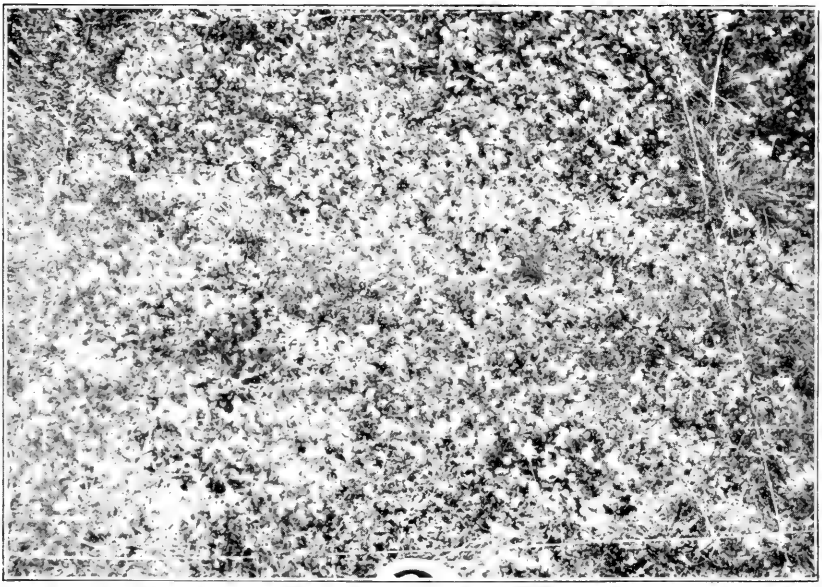
9. Pasture Cutting Tests 1a.

Taken at commencement of cutting in June, 1927. Note abundant soil cover. Principal species at this state *Erodium botrys*, with occasional Danthonia plants.



10. Pasture Cutting Tests 1b.

Taken November, 1928, prior to final cut of series, and after two seasons of fortnightly cutting. Note sparseness of vegetation, large amount of bare soil, and high percentage of weeds.



11. Pasture Cutting Tests 3.

Taken November, 1928, prior to final cut of Series 3, and after two seasons of cutting at seven-weekly intervals. Note absence of bare soil and abundance of vegetation. Dominant species an annual clover, *Trifolium arvense* (in flower).

12. Pasture Cutting Tests 2.

Taken November, 1928, prior to final cut of Series 2, and after two seasons of four-weekly cutting. The herbage is again sparse, but Clover (in flower) and Danthonia are still present and less bare soil is evident than in Series 1.

13. Weighing Sheep at Waite Institute.

14. View of Grass Garden and Meteorological Enclosure at Waite Institute.

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COMMONWEALTH OF AUSTRALIA

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Progress Report
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CONTENTS.

The Influence of Frequency of Cutting on the Productivity, Botanical and Chemical Composition, and the Nutritive Value of "Natural" Pastures in Southern Australia.*

1. Introduction.

Comparatively little attention has been hitherto devoted in Australia to the study of pastures in relation to animal nutrition. From time to time, the introduction of fodder species has been undertaken with a view to pasture improvement, whilst the application of phosphatic fertilizers has been demonstrated to effect much improvement both in the productivity and carrying capacity of the pastures. Pasture management has not hitherto been a subject of critical study, chiefly because the grazing of stock has been conducted on an extensive, rather than an intensive, scale. The change from extensive to intensive use of pasture lands is, however, making some headway, especially in the regions of higher rainfall. It is desirable, therefore, to investigate methods of management likely to give increased returns, and to ascertain the reaction of the pasture complex under more intensive grazing.

The pasture complex is the resultant of the interplay of climatic, soil, and biotic factors: the latter including pasture management. Pasture management is within the control of the grazier, and the soil factors are subject to considerable modification at his hands. The profound changes in pasture type that can be achieved by management and controlled grazing are becoming increasingly realized. Hence an understanding of the influence of the chief factors concerned on the yield, botanical composition, and nutritive value of the pasture, becomes an essential preliminary to the adoption of any modified system of husbandry.

The present investigation is regarded by the authors as a preliminary step in the elucidation of the problems of increasing the productivity of "natural" pastures by changes in management.

The term "natural" pasture is used to designate a pasture that has developed under the combined influence of man and of the grazing animal, but without the sowing down of herbage species. These pastures are typical of the coastal belt of Southern Australia. In composition they vary considerably, but are characterized by the presence of substantial percentages of exotic herbaceous annuals, including the small annual clovers and medics, in conjunction with endemic, slow growing, perennial species of *Danthonia* and *Stipa*.

The climatic conditions for which the present results are significant are essentially those of a long, dry summer period, characteristic of the Southern temperate zone of Australia. This zone is that of winter rainfall, growth being almost wholly confined to the six months from

* Typescript received for publication, 8th October, 1930.

mid-May to mid-November. For the remainder of the year, intense climatic conditions resulting in high evaporation, combined with low sporadic rainfall, prevail. Pastures are in a dry, matured state during this period, and in such a condition form the available stock feed.

In the present investigation, information on the following specific points was sought :—

(1) The total yield of dry matter from pasture subjected to different frequencies of cutting, designed to represent different intensities of grazing by stock.
(2) To what extent the yield of dry matter from such a system of pasture cuts could be correlated with meteorological conditions.
(3) The seasonal growth of the pasture.
(4) The botanical composition of the pasture under the different frequencies of cutting.
(5) The variation in the mineral content of the pasture under the different frequencies of cutting.
(6) The nutritive value of pasture at varying growth stage, and the effect of the different systems of cutting on the total yield of nutritive material.

2. Technique.

The experiment was laid down in April, 1927, and concluded in November, 1928. The investigations extend over the two growing seasons 1927 and 1928.

For the purpose of the experiment, an area of "natural" pasture at the Waite Institute was selected. The pasture lies at the base of the foothills of the Mount Lofty Range, the average annual rainfall being 23 inches, approximately 17 inches of which are received during the six winter months. The soil is a medium heavy, red clay loam, with the following mechanical and chemical analyses :—

(The data given have been kindly provided by Mr. C. S. Piper, M.Sc., who has conducted the chemical and mechanical analyses of the soil.)

Mechanical and Chemical Analyses of the Soil.

(1) Mechanical Analysis : 0–9 inches. Horizon A.

Coarse sand	7·5%
Fine sand	31·9%
Silt	16·6%
Fine silt	23·1%
Clay	12·5%
Loss on acid treatment	0·6%
Loss on ignition	4·6%
Moisture	1·8%
	98·6%

(2) Chemical Analysis: 0–9 inches. Horizon A.
9–18 inches. Horizon B.

	0–9″	9–18″
Fe_2O_3	3·68%	6·05%
Al_2O_3	5·24%	10·03%
CaO	0·17%	0·23%
MgO	0·64%	1·04%
K_2O	0·72%	1·01%
MnO_2	0·08%	0·05%
P_2O_5	0·042%	0·044%
T_1O_2	0·14%	0·17%

No records of the area are available prior to 1925, but it is probable that it has been in pasture for upwards of 40 years. In 1925 and 1926, the pasture was top-dressed with superphosphate at the rate of 20 lb. of P_2O_5 to the acre. No fertilizers were applied during the course of the experiment.

Fifty plots, each a square metre in area, were laid down in two blocks. Within each block the plots were randomly distributed on the Latin square system. Five cutting treatments were employed, with ten replications of each treatment. Paths 1 metre wide were employed between the plots, with a 2-metre path between the blocks. The outlines of the plots were marked by 10-gauge fencing wire drawn taut between angle-iron pegs driven firmly into the ground. The whole was finally enclosed by a stock-proof fence.

The five treatments were as follows:—

Series 1.—10 plots. Cut at fortnightly intervals.
Series 2.—10 plots. Cut at monthly intervals.
Series 3.—10 plots. Cut at seven-weekly intervals.
Series 4.—10 plots. Cut at ten-weekly intervals.
Series 5.—10 plots. Cut at completion of growing season.

During 1927, the cutting of the plots was made by hand shears, but in 1928 a specially adapted two-stand portable shearing machine was used. In both seasons the herbage was cut at an approximate height of ½″ above ground level.

Prior to the experimental period in 1927, a clearing cut was made, and in 1928 two clearing cuts were necessary. The first was made on 17th April, to remove dead dry roughage, whilst the second was made on 14th June, to clear away some growth of *Inula graveolens* (Stinkwort) and *Linaria elatine* (Pointed Toadflax) which had appeared after the first cut. The clearing cuts also ensured that all series commenced growth from an uniform basis.

The herbage cut from each plot was carefully collected and placed in separate containers. In the laboratory, the samples were hand-cleaned, all particles of soil and other extraneous matter being removed. In 1927, the samples were botanically analyzed by hand separation of the species; the labour involved was, however, too great, and the botanical data are not complete for this season. During 1928, the percentage estimation method of botanical analysis was employed, and the data for this season are complete. All samples were dried to constant weight at 102° C. For chemical anaylses, the ten replicates for each treatment were bulked, and a representative sample of approximately 250 grams dry weight retained.

Whilst the technique employed is designed as far as possible to imitate grazing by stock, it is to be noted that no system of cutting can be identical in effect with that of the grazing animal.

(*a*) Animals, particularly sheep, graze selectively. Cutting has also a very distinct selective action, but of a different nature. Whereas sheep select leafage and young succulent shoots, the shears remove a greater percentage of the aerial portions of species with an erect habit of growth than of rosette and prostrate species.

(*b*) Sheep, on the one hand, graze only part of the leafage, leaving a certain amount of photosynthetic material, enabling the plant to recover more rapidly. The shears, on the other hand, remove at one operation every portion of the plant to a given level, thus weakening the plant to a greater degree.

(*c*) Grazing is continuous, whereas the cutting is intermittent. Data are given which tend to show that, owing to the marked differences in seasonal growth of the constituent species of a pasture, the precise date of cutting has a marked influence on the botanical composition. The cutting of early-growing species, already well established, would greatly lessen competition, and thus enable the later growing species to have a better opportunity for development.

(*d*) The absence of consolidation and trampling is another factor that makes for discrepancy of conditions.

(*e*) Finally, there is no return to the soil of organic and mineral substances under a system of cutting, whereas there is a continuous return of some considerable quantities of these materials in the excreta of the grazing animals.

3. The influence of different frequencies of cutting on the gross yield of dry matter produced during the season.

The gross yields of herbage produced during 1927 and 1928 under the five treatments are given in Table 1, and shown graphically in Figure 1. The yields are expressed as pounds dry matter per acre, and are the mean yields calculated from the ten replications.

A higher yield was obtained in 1927 than in 1928 under all treatments. Two factors are held to contribute to this result. Firstly, the residual effect of the superphosphate applied in 1925 and 1926 would be more pronounced in 1927 than in 1928. Secondly, the rainfall during August, 1928, was 84 points, whereas 412 points fell in August, 1927. Although the total rainfall during the growing period in 1928 was 1,642 points as against 1,505 points in 1927, the low rainfall at the critical spring period would have a marked influence in depressing the total yield of the season 1928.

Season 1927.– The total dry matter produced when the pasture was cut at fortnightly intervals was 1,715·6 lb. per acre. From the monthly cuts 1,663·0 lb. per acre were obtained. In Series 3, cut at seven-weekly intervals, the total production was 2,262·5 lb. per acre. Series 4, cut at intervals of ten weeks, gave a much lower yield, being 1,732·6 lb. per acre. Maximum yield was obtained from Series 5, when the pasture was cut once only, 2,283·9 lb. per acre being obtained.

It is difficult to draw definite conclusions from the above data as to the effect of the cutting in the intermediate series. The incidence of the cutting in relation to the stage of growth of the constituent species, together with the meteorological conditions prevailing during the growth period, has an important bearing on the yield from any given series. The low yield in Series 4, 1927, is held to be partly due to the fact that the first cut of this series was made in the second week of September, thus injuring the species at the critical pre-flowering stage, resulting in partial non-recovery and low yield for the second cut. It is apparent from the data, however, that Series 5 produced a significantly higher total yield than Series 1, where the pasture was subjected to the fortnightly cuts.

Season 1928.—Reference to Table 1 and Figure 1 will show that in 1928 a gradual increase in total dry matter produced obtains the less the number of cuts made.

The lowest yield, 968·9 lb. per acre, is obtained when the pasture is cut at fortnightly intervals (Series 1). Monthly cuts show a definite increase in the yield, 1,337·3 lb. per acre of dry matter being obtained. A slight increase to 1,340·0 lb. per acre was obtained from Series 3, cut at seven-weekly intervals, whereas a definite increase to 1,514·9 lb. per acre was obtained from Series 4. Maximum production, 1,531·6 lb. per acre, was obtained from Series 5, where the pasture was cut once only.

In general, taking the data for both seasons into consideration, it is clear that the more severe the cutting the less the gross yield of dry matter produced. The reduction in yield is most marked when the pasture has been subjected to cutting at fortnightly periods. It would appear that cutting the pasture three times during the season does not seriously reduce the total production, the average yield for both seasons from Series 3 being 1,801 lb. per acre, as against 1,907·7 lb. per acre from Series 5.

4. The seasonal variation in the yield of dry matter produced and the influence of rainfall and of temperature on the yield.

For the purpose of estimating the influence of rainfall and temperature on the yield of dry matter cut from the pastures, the data from the fortnightly cuts in 1928 are used. The rainfall is given in terms of points 1 point = 1/100th inch), and the total for each fortnightly period from

31st May, 1928, to 19th November, 1928, is given in the last column of Table 8. For the purpose of measuring the influence of temperatures on the yield curve, the mean daily maximum temperature for each fortnightly period has been plotted in Figure 3.

The graph of the seasonal yield from the fortnightly cuts of Series 1, 1928, is set out in Figure 2, where the yield in pounds dry matter per acre is given for each fortnightly period, commencing on 29th June, 1928. Each point on the curve represents the mean yield obtained during the preceding fortnight. The rainfall for each fortnightly period from 14th June is also given in Figure 2, the points on this graph representing the total rainfall (in 1/100ths inch) during the preceding fortnight.

The yield for the first fortnight is 56·12 lb. per acre; there is a decrease for the second and third cuts, the yields being 29·26 lb. per acre and 31·49 lb. per acre respectively. With the exception of the sixth cut, viz., 8th September, the yield of dry matter increases rapidly to the maximum production of 203·14 lb. per acre in the ninth period (9th–20th October). For the two remaining cuts, the yield drops markedly, and on 19th November, the date of the last cut, the pasture was completely dried up and no further growth possible.

The high peak of production during the three periods from 9th September to 20th October is noteworthy. The total production of dry matter for the season is 968·9 lb. per acre, and during the three periods given, 505·85 lb. per acre were produced; representing 52·2 per cent. of the total dry matter produced during the whole season. This peak of production coincides with the flowering period of the pasture species, and at this time, also, both rainfall and temperature conditions approached their optimum.

5. The influence of rainfall upon yield.

The rainfall for the first period of cutting, 14th June to 28th June, was 164 points, following upon a precipitation of 294 points in the preceding fortnight. The yield of dry matter was 56·12 lb. per acre.

In the second period, 29th June to 12th July, the rainfall was 43 points. The yield obtained was 29·26 lb. per acre.

During the third period, 13th–26th July, the rainfall increased to 281 points, whereas the yield was but slightly greater than during the second period, being 31·49 lb. per acre.

For the fourth period, 27th July to 9th August, the rainfall was exceptionally light, 9 points only being received. The yield of dry matter for this period was, however, 80·21 lb. per acre.

It becomes apparent, therefore, that there is a lag in the effect of the rainfall on the yield. From the data obtained during the first four periods, the rainfall of the preceding fortnightly period influences, to a marked degree, the total yield of dry matter produced during any given period. The yield curve follows closely the rainfall curve, but is a fortnight later in expression.

The yield for the fifth period was 83·77 lb. per acre, only slightly more than the yield of the fourth period. The effect of the very light rainfall during the fourth period is not marked. This is due to the carry-over effect of the high rainfall obtained during the third period, when 281 points of rain fell. Reference to Figure 3 will show that during the third and fourth fortnightly periods, temperatures were relatively low, and therefore the rain falling during the third period would be particularly effective because of low evaporation.

For the fifth period, the rainfall is again fairly low, 57 points being received. Combined with low rainfall of the fourth period, this has a marked effect in decreasing the yield for the sixth period to 51·66 lb. per acre. The rainfall for the sixth period was 107 points.

It will be noted from Figure 3 that the mean daily maximum temperatures were over 10° F. greater in the fifth period than in the fourth. This increase of temperature at this period is followed by a very marked rise in production of dry matter. The effect of the increased temperature at this stage is not, however, immediately apparent. This is due to the fact of the low rainfall in the fourth and fifth periods seriously limiting the yield.

In the seventh period the yield is 146·40 lb. per acre, both rainfall and temperature approaching the optimum. During the seventh period the rainfall is low, 48 points only being received. The mean temperature during this period is 65·8° F.

For the eighth period the yield is slightly greater at 156·31 lb. per acre, the effect of the low rainfall during the seventh period being apparent, in that the increased rate of production was not maintained. The rainfall was the heaviest during any period of the season, reaching 293 points.

In the ninth period the maximum production of dry matter followed upon the maximum rainfall of the eighth period ; 203·14 lb. per acre of dry matter being harvested. The rainfall for the ninth period fell to 43 points.

The yield in the tenth period greatly decreased to 86·63 lb. per acre, and was the result of the low rainfall during the ninth period, combined with rising temperatures. The rainfall for the tenth period was 87 points.

The yield during the eleventh and final period was 43·81 lb. per acre, the rate of decrease being less than the previous period, due to the increased rainfall of 87 points. The temperature became the limiting factor during this period, increasing from 68·4° F. in the tenth period to 75·3° F. in the eleventh. At the latter temperature the pastures became completely dried off, and no further growth was possible. The rainfall for the final period was only 4 points, which amount was totally inadequate for promoting further growth.

The cuts were therefore concluded on 19th November.

It is apparent that the rainfall is the chief meteorological factor in influencing the growth of natural pastures under the conditions of the experiment. Temperature exerts a pronounced modifying influence throughout, and at the end of the season both rainfall and temperature act as limiting factors to growth, resulting in the drying off of the pasture. There is a lag of approximately a fortnight before the effects of rainfall are reflected in the yield.

During the earlier part of the season, rainfall is not as effective as during the spring months. The temperatures at this period are low, and growth is limited. It is seen from the data in Figure 3 and Table 8 that the optimum mean daily maximum for growth is approximately 65° F. In the earlier part of the season the mean daily maximum falls below 60° F., excepting only the first fortnightly period. Growth is slow at these temperatures.

In the final period of the season the temperatures rise to over 75° F., at which figure the pasture species become dried off, due to the very rapid drying out of the soil moisture.

6. The effect of the different systems of cutting on the aggregate yield of the major species constituting the pasture.

The data presented is for the 1928 season only. Botanical analyses, using the percentage estimation method, were made on each sample from every cut during the season. The weights of the species are calculated from the mean botanical composition of the cuts and the total yield of dry matter.

The aggregate production of the major species and species groups under the five different systems of cutting are set out in Table 3, and expressed graphically in Figure 4. The yield are given in lbs. dry matter per acre in all cases.

It will be convenient to deal with each species and species group individually.

A. *Erodium botrys.*

It is seen that there is a decrease in the yield of *Erodium botrys*, with decreasing frequency of cutting. In Series 1, where the cuts were made at fortnightly intervals, a total yield of 645·30 lb. per acre was obtained. In Series 2, monthly cuts, 598·51 lb. per acre, were produced. Series 3 gave 565·48 lb. per acre ; Series 4, 478·12 lb. per acre. The lowest yield, 337·64 lb. per acre, was obtained when the pasture was cut once only in Series 5.

Thus under a system of fortnightly cuts, the gross yield of dry matter of *Erodium botrys* was slightly less than double the amount obtained when the pasture was cut once only. In view of the fact that the total production from the pasture was very much less under fortnightly cutting, this result is somewhat remarkable. *Erodium botrys* is a "rosette" species, the rosette adhering closely to the ground, particularly in the earlier stages of growth, or when subjected to repeated cutting. A greater proportion of the aerial part of the plant remains, therefore, when cuts are made than is the case with the more erect growing species. This enables the injured plants to recover more quickly and to recommence growth. Further, the greater injury done to the erect species by the cutting very materially inhibits their growth and therefore reduces their competitive effect on *Erodium*. This results in this species taking up the greater proportion of ground, the more severe the cutting, and actually results in greater production than when the other constituent species are allowed to exercise their full competitive effect for light and food material.

B. *Danthonia penicillata.*

This species forms erect tufts which receive very severe treatment during the cutting. The greater proportion of the aerial organs are removed at each cut. The effect of repeated cutting on this species is to reduce markedly the total yield of dry matter produced. With *Danthonia penicillata*, the more frequent the cutting the less the yield. The total production when cut once is 183·78 lb. per acre, whereas when it is subjected to a system of fortnightly cuts in Series 1 the yield is but 12·85 lb. per acre.

C. *Echium plantagineum.*

During the early part of the season, this species is a closely adpressed rosette, but the young crowns are injured very severely at each cut, because the rosette is much larger than is the case with *Erodium botrys*, the crown being more accessible. This results in the maximum production being obtained from a single cut, the total yield being 387·60 lb. per acre in Series 5, whereas it is 55·31 lb. per acre in Series 1, with a gradual increase in yield with decreasing severity of cutting.

D. *Annual Grasses.*

The annual grasses consist mainly of *Festuca bromoides*, small quantities of *Briza minor; Aira caryophyllea*, and *Lolium rigidum* being present.

In habit of growth each of these species is erect. In Figure 4 are shown the aggregate yields from the annual grasses under the five different treatments. It will be noted that with increased severity of cutting, the production of dry matter falls very markedly, maximum production being obtained with one cut during the season.

E. *Leguminosae.*

The Leguminosae have been grouped together for convenience of study. The following species were present, and are recorded in order of abundance :—

Trifolium arvense, Trifolium procumbens, Trifolium glomeratum, Trifolium angustifolium, Trifolium striatum, Trifolium subterraneum, Medicago tribuloides, Vicia sativa.

An interesting feature is that the maximum yield of legumes is produced when two cuts are made (Series 4), there being a marked decrease in the aggregate yield from one cut.

Reference to Tables 4, 5, 6, and 7 will show that there is a well marked rise in the percentage production of legumes as the season advances, in all series the greater part of the yield being obtained in the spring.

The frequent cutting in Series 1 reduces the yield very considerably, but there is little difference in the effect of the cutting in Series 2 and Series 3.

The first cut of Series 4 was made on 25th August. The legumes at this time were just commencing growth, constituting only 5 per cent. of the total yield of herbage produced. The majority of the other species on the plots had made appreciable growth at this time, more particularly *Erodium botrys*, *Danthonia penicillata*, and *Echium plantagineum*. These species therefore received greater injury than the legumes, thus greatly reducing their competitive effect. This resulted in a very marked increase in the legume content of the second cut, due to the greatly decreased competition of the earlier growing species at the time the legumes commenced active growth.

In Series 5, the earlier growing species were not removed at this critical stage, thus materially hampering the growth of the legumes, resulting in a lower aggregate production than in Series 4, when two cuts were made during the season.

F. *Romulea parviflora.*

This species is an early season grower, and the effect of the different systems of cutting was not marked.

G. *Miscellaneous plants.*

In the aggregate yield, the miscellaneous species did not contribute to any marked extent to the yield. The figures obtained do not warrant any definite conclusion, but presumably owing to the varied botanical characters of the constituent species of this group, the systems of cutting did not influence the total production to any degree.

7. The variation in mineral content of the herbage from the different frequencies of cutting.

In Table 9 is shown the mean percentage of the mineral constituents in the herbage harvested from each of the five series. For 1927 the analyses were confined to CaO and P_2O_5, but in 1928 complete mineral analyses of the herbage were made.

The percentages of all constituents have been calculated on the 100 per cent. dry matter basis. The dry matter was estimated by redrying at 100° C. to constant weight.

The data for total ash have not been included. These were not reliable owing to the unavoidable inclusion of traces of soil which could not be removed in the cleaning of the samples. The figures for silica free ash, however, form a reliable index of the total minerals present in the herbage, because the included soil was relatively insoluble in the dilute acid employed in the extraction.

Season 1927.

(*a*) *Calcium.*—The highest percentage of CaO (2·05%) was obtained in Series 1. The lowest percentage (1·44%) was obtained in Series 5.

With the exception of Series 2, there appears to be a tendency for the CaO to decrease with the decreased frequency of cutting.

(*b*) *Phosphorus.*—The phosphorus content of Series 1 and Series 2 is almost identical in 1927. Series 3 is distinctly lower, the P_2O_5 percentage diminishing uniformly from Series 3 to Series 5.

Season 1928.

(*a*) *Calcium.*—The percentage of calcium shows quite considerable variation, but does not seem to be influenced to any marked degree by the stage of maturity of the herbage.

(*b*) *Phosphorus.*—Again there is no significant difference between the phosphorus content of Series 1 and Series 2, indicating that for a period of upwards of a month the intake of P_2O_5 is fairly constant. Series 3 is, however, markedly lower in P_2O_5 content, whilst the decrease is definite from Series 3 to Series 4 and from Series 4 to Series 5.

(*c*) *Potassium.*—The K_2O content shows a gradual decrease with decrease in the frequency of cutting indicating that the intake of K_2O by the pasture species is more active during the young stages and becomes progressively less with the onset of maturity.

(*d*) *Sodium.*—The Na_2O content is relatively high for all series and shows a tendency to increase with the increasing maturity of the herbage.

(*e*) *Chlorine.*—The chlorine content falls from Series 1 to Series 4. whilst there is an appreciable increase from Series 4 to Series 5.

(*f*) *Silica free ash.*—The highest percentage of silica free ash is obtained in Series 1. In Series 2 and Series 3 the content is similar, but appreciably lower than for Series 1. Series 4 shows an increase as compared with Series 2 and 3, whilst the lowest percentage is obtained in Series 5.

8. Discussion of the influence of stage of maturity of the herbage on the CaO and P_2O_5 content.

Calcium.—In 1927 the calcium content of the herbage tended to diminish with decreased frequency of cutting, whereas in 1928 the calcium content remained at a high level in all series. In view of the considerable fluctuation in the lime content as between series and series in both seasons, it is difficult to establish the precise influence of the different frequencies of cutting on the calcium content.

In all cases, however, the calcium content is high compared with the results of Cruickshank (1), Fagan *et al.* (4), and Godden (5) for British pastures, and are very high compared with Staples and Taylor's (9) figures for veldt in Natal.

The most important factor contributing to this high lime content is the high proportion in the pasture of species rich in lime. Reference to Table 3 will show that *Erodium botrys*, *Echium plantagineum*, and the leguminous species are the major constituents of the cut herbage under all treatments. Analyses of *Erodium botrys* and *Echium plantagineum* at the Waite Institute have shown that both these species are very rich in lime, the former being frequently as high as 4% CaO, whilst the latter species is frequently between 3% and 4% CaO. Whilst analyses of the annual clovers growing in the pasture are not available, analyses of subterranean clover and other leguminous species has shown them to be particularly rich in lime.

Phosphorus.—In both 1927 and 1928, the percentage of P_2O_5 in the herbage remains almost identical in the fortnightly and monthly cuts. With less frequent cutting, however, the phosphorus content drops markedly and consistently, the mature herbage in Series 5 containing 0·23% and 0·27% in 1927 and 1928 respectively, as opposed to 0·57% and 0·48 in Series 1.

In all cases the P_2O_5 content is low compared with the figures of European investigators for good pastures, but is somewhat similar to the figures of Cruickshank (1) for poor pastures.

The figures of Staples and Taylor (9) for veldt cut at fortnightly intervals show a somewhat lower percentage of P_2O_5, but their figures for four months old veldt are very similar to the present figures for Series 5. Eight months old veldt is distinctly inferior in P_2O_5 content.

9. The mineral content of the herbage from the fortnightly cuts of Series 1.

In Table 10 is shown the mineral content of each of the fortnightly cuts in 1927 and 1928. The CaO content in both seasons fluctuates markedly, but there is no well-defined seasonal variation. On the whole the percentage of CaO remains at a high level throughout the season.

The P_2O_5 content fluctuates from cut to cut, but again there does not seem to be any definite trend. This is in marked contrast to the behaviour of this constituent when the pasture is allowed to grow to successive stages of maturity. The evidence strongly suggests that the P_2O_5 content of a pasture can be maintained at a consistently high level by frequent cutting or grazing, thus retaining the pasture at an immature stage.

In 1928 the percentage of potassium is fairly well maintained up to the eighth harvest; thereafter a slight reduction is noted.

The chlorine content varies in an erratic manner, but in the main it tends to rise, being opposite in behaviour from its variation with stage of maturity.

The percentage of sodium exhibits a tendency to fall through the season, whilst with increasing maturity of the herbage it tends to rise.

The silica-free ash varies in an erratic manner, but within fairly narrow limits. On the whole, it tends to remain at the same level throughout the season.

The Calcium-phosphorus ratio.—The calcium-phosphorus ratio is in all cases particularly high. This is largely the result of the high values obtained for calcium. The mean ratio for Series 1 in 1927 is 3·7, while in Series 5 it reaches the high value of 6·3. Theiler, Green, and du Toit (10) have shown that the minimal requirement of cattle for phosphorus is higher than for calcium, and state that " a ratio of P_2O_5 to CaO so high as three to one is not necessarily disadvantageous." These authors, however, stress the fact that the animal has considerable physiological capacity to adjust itself to varying rations of the mineral balance, whilst realizing that a particular ratio may represent the optimum.

The pasture under investigation would not have the most efficient balance of calcium and phosphorus, particularly in the more mature herbage. The ratio is, however, much improved in the less mature herbage from the frequent cutting treatments, but it is still wide.

10. The total production of calcium, phosphorus, and nitrogen under the different frequencies of cutting.

The total yield in pounds per acre of calcium, phosphorus, and nitrogen for the five series is shown in Figure 5 for 1927 and 1928. The yield of all three constituents was higher in 1927 than in 1928, but this was mainly due to the higher yields of dry matter in 1927.

In 1927, the maximum production of calcium was in Series 3, whilst in 1928 maximum production was from Series 4. The tendency is for the total yield of calcium to rise with decreased severity of cutting.

The production of phosphorus is greatest in Series 3 in 1927 and Series 2 in 1928. Frequent cutting appears to produce more phosphorus, but the severe cutting at fortnightly intervals so seriously depletes the yield of dry matter as to diminish the total yield of P_2O_5 per acre.

The maximum production of nitrogen is obtained from Series 1 in 1927 and Series 2 in 1928. whilst the lowest yield of nitrogen is obtained in Series 5 in spite of the much higher yield of dry matter. Shutt and his co-workers (8) showed that maximum production of protein was obtained from pasture cut at three-weekly intervals, whilst Fagan *et al.* (4) have shown that the yield of protein from an unmanured ley at Aberystwyth was nearly twice as great from monthly cuts as from weekly cuts.

Staples and Taylor (9) record that the highest yield of crude protein was obtained by them from the monthly cuts, and the lowest yield from the mature herbage.

The results recorded here are in substantial agreement with the findings of the above investigators, and show that from the point of view of maximum production of protein per acre the herbage must be utilized in the young state. The optimum stage would appear to be a month-old pasture.

11. The nutritive value of the pasture cuts.

No digestibility trials were conducted in conjunction with the experiment. The caloric values given in Table 11 have been calculated according to the formula used by Godden (5), the digestion coefficients being approximated. The mean values for ether extract, crude protein, crude fibre, and nitrogen-free extractives for both seasons are tabulated in Table 11.

In 1927, the ether extract tends to rise to a maximum on passing from Series 1 to Series 3, and thereafter falls. In 1928, the maximum ether extract is obtained in Series 2, decreasing gradually to Series 5.

In 1927, a decrease in the percentage of crude protein occurs from Series 1 to Series 5, where it is but 35 per cent. of the value for Series 1. In 1928, a similar reduction is obtained, but is not so marked, the value for Series 5 being 54 per cent. of that in Series 1.

In both seasons, the crude fibre increases markedly with decreased severity of cutting, indicating that the fibre content rises with the onset of maturity in the pasture. The variation in the percentage crude fibre and crude protein in the five series is shown in Figure 6.

The nitrogen-free extractives are very similar throughout for all series, slight fluctuations being noted.

The caloric values show a distinct tendency to fall from Series 1 to Series 5 in both seasons, although the figures obtained for each series are considerably different for the two seasons.

12. Conclusions.

(1) The highest yield of dry matter is obtained from a natural pasture by allowing the herbage to reach maturity. More frequent cutting tends to reduce the yield, fortnightly cuts seriously depressing the dry matter produced per acre. Pasture cut three times during the season yielded approximately 94 per cent. of the yield obtained from one cut, and produces herbage of higher nutritive value and lower fibre content than mature herbage.

(2) During the greater part of the season, rainfall is the most important factor governing the yield from fortnightly cuts. There is a lag in the effect of rainfall on yield. The yield of a given fortnight being greatly influenced by the rainfall during the preceding fortnight.

(3) Throughout the season, temperature exerts a profound modifying influence, and during July seriously limits the growth of the pasture. Towards the end of the season both temperature and rainfall become limiting factors to growth.

(4) Severe defoliation is demonstrated to reduce the yield of the erect species, whilst certain rosette species, e.g., *Erodium botrys*, give a higher yield per acre when the pasture is cut at fortnightly intervals.

(5) The calcium content of the herbage is high. This is attributed to the high proportion of species rich in lime that constituted the herbage from all series.

(6) The different frequencies of cutting do not appreciably influence the lime content of the herbage.

(7) The highest production of lime per acre is obtained when the pasture is cut at intervals of 6–8 weeks.

(8) The percentage of P_2O_5 in the herbage is low compared with the percentages obtained from Continental pastures. It is, however, very

similar to the results obtained from certain South African pastures. The highest production of P_2O_5 is obtained from Series 3 in 1927 and Series 2 in 1928.

(9) The P_2O_5 content of fortnightly and monthly cuts is almost identical. With less severe cutting, however, the P_2O_5 content drops markedly to a minimum in the herbage at maturity.

(10) The P_2O_5 content is maintained throughout the season when the pasture is cut at fortnightly intervals.

(11) The calcium-phosphorus ratio is very high in all cases, but is reduced when the pasture is cut at fortnightly intervals.

(12) The herbage from fortnightly and monthly cuts is more than twice as rich in crude protein as the mature herbage from a single cut.

(13) The highest production of crude protein is obtained from pasture cut at 2–4 weekly intervals, the higher protein content of the young herbage more than counterbalancing the depressed yield.

(14) Pasture cut at fortnightly intervals is lowest in percentage crude fibre. With decreased frequency of cutting, the crude fibre content steadily rises.

13. Acknowledgments.

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TABLE 1.—Showing total yield of dry matter produced on each series in seasons 1927 and 1928. Yield expressed as lb. per acre, and gms. per sq. metre.

Season.	Series 1.		Series 2.		Series 3.		Series 4.		Series 5.	
	Gms. per sq. metre.	Lb. per acre.	Gms. per sq. metre.	Lb. per acre.	Gms. per sq. metre.	Lb. per acre.	Gms. per sq. metre.	Lb. per acre.	Gms. per sq. metre.	Lb. per acre.
1927 ..	192·3	1715·6	186·4	1663·0	253·6	2262·5	194·2	1732·6	256·0	2283·9
1928 ..	108·6	968·9	149·9	1337·3	150·2	1340·0	169·8	1514·9	171·7	1531·6
Mean ..	..	1342·3	..	1500·2	..	1801·2	..	1623·7	..	1907·7

TABLE 2.—Showing mean yield of dry matter in successive cuts from each series. Yields expressed in lb. per acre. Season 1928.

Series 1.		Series 2.		Series 3.		Series 4.		Series 5.	
Date of Cut.	Yield.	Date of Cut.	Yield.	Date of Cut.	Yield.	Date of Cut.	Yield.	Date of Cut.	Yield.
29th June	56·12	..	..	..	..	..	..	..	..
13th July	29·26	13th July	81·01	..	..	..	..	..	..
27th July	31·49	..	..	27th July	107·06	..	..	..	..
10th Aug.	80·21	10th Aug.	155.06	..	..	..	..	..	..
25th Aug.	83·77	..	..	..	..	25th Aug.	470·26	..	..
8th Sept.	51·66	8th Sept.	192·99	..	..	..	..	..	..
22nd Sept.	146·40	..	..	15th Sept.	537·17	..	..	..	..
8th Oct.	156·31	8th Oct.	555·99	..	..	..	..	..	..
20th Oct.	203·14	..	..	..	..	..	..	..	..
5th Nov.	86·63	..	..	..	..	..	..	..	..
19th Nov.	43·81	19th Nov.	353·47	19th Nov.	694·27	19th Nov.	1044.72	19th Nov.	1531·84

TABLE 3.—Showing total dry weight of each species produced during season 1928 on each of the five series. Calculated from yield of dry matter and percentage botanical composition. Expressed in lb. dry matter per acre.

Species and Species Groups.	Series 1.	Series 2.	Series 3.	Series 4.	Series 5.
Danthonia penicillata ..	12·85	79·40	87·18	61.81	183.78
Erodium botrys	645·30	598·51	565·48	478.12	337.64
Echium plantagineum ..	55·31	49·60	144·38	172.52	387.60
Romulea parviflora ..	19·81	40·33	28·30	68.61	28.56
Annual grasses	14·90	47·82	54·28	84.14	125.10
Leguminosae	143·64	428·28	408.42	569.95	419.80
Miscellaneous species ..	77·08	93·41	51.85	79.49	49.08

TABLE 4—Showing average botanical composition of Series 1 through season 1928. Expressed as percentage of total dry weight.

Species and Species Groups.	Date of Cut.										
	29th June.	13th July.	27th July.	10th Aug.	25th Aug.	8th Sept.	22nd Sept.	8th Oct.	20th Oct.	5th Nov.	19th Nov.
	%	%	%	%	%	%	%	%	%	%	%
Danthonia penicillata	1·5	3·0	4·6	2·3	1·4	1·5	0·5	1·1	0·6	Tr.	5·2
Erodium botrys ..	79·0	70·0	60·0	68·0	73·8	64·0	61·6	55·5	80·3	67·4	32·3
Echium plantagineum ..	4·0	12·0	9·2	6·5	7·5	7·9	4·7	4.9	2.6	9.3	7.4
Romulea parviflora	13·0	6·2	2·7	4·1	3·6	3·4	1·5	Tr.	..	..	..
Annual grasses ..	Tr.	0·4	1·4	1·9	1·7	3·5	2·2	1·0	0·6	0·5	8·0
Leguminosae ..	Tr.	0·9	1·7	2·6	4·2	13·4	21·2	29·8	11·1	16·2	38·0
Miscellaneous species	3·0	7·5	20·4	15·2	7·6	6·7	8·5	7·4	5·3	6·6	9·6

TABLE 5.—Showing average botanical composition of monthly cuts. Series 2, 1928. Expressed as percentage of total dry weight per cut.

Species and Species Groups.	Date of Cut.				
	13th July.	10th Aug.	8th Sept.	8th Oct.	19th Nov.
Danthonia penicillata ..	18·2	14·4	9·0	2·6	3·3
Erodium botrys	50·9	53·2	53·4	49·8	26·8
Echium plantagineum ..	5·2	7·1	5·3	1·6	4·4
Romulea parviflora ..	11·8	14·4	4·4	0·1	Tr.
Annual grasses	0·4	2·9	4·2	2·2	6·4
Leguminosae	1·1	5·4	18·9	39·2	46·5
Miscellaneous species ..	12·2	2·6	4·9	4·4	12·9

TABLE 6.—Showing average botanical composition of successive cuts. Series 3, 1928. Expressed as percentage of total dry weight per cut.

Species and Species Groups.	Date of Cut.		
	27th July.	15th September.	19th November.
Danthonia penicillata ..	20·0	8·4	3·0
Erodium botrys	45·7	54·2	33·2
Echium plantagineum ..	18·2	11·3	9·7
Romulea parviflora	10·8	3·1	..
Annual grasses	0·6	4·0	4·7
Leguminosae	1·5	16·6	46·6
Miscellaneous species ..	2·7	2·8	5·0

TABLE 7.—Showing the average botanical composition of herbage from ten plots of Series 4 and Series 5 at each cut, 1928. Expressed as percentage of total dry matter produced.

Species and Species Groups.	Date of Cut.		
	Series 4.		Series 5.
	25th August.	19th November.	19th November.
Danthonia penicillata ..	6·1	3·2	12·0
Erodium botrys	47·9	24·3	22·0
Echium plantagineum ..	16·6	9·1	25·3
Romulea parviflora	14·6	Tr.	2·0
Annual grasses	3·5	6·5	7·7
Luguminosae	5·2	52·3	27·4
Miscellaneous species ..	5·9	5·0	3·1

TABLE 8.—Showing the mean daily temperatures for the fortnightly periods, together with the rainfall in points for the corresponding periods, 1928.

Period.	Mean Maximum.	Mean Minimum.	Rainfall in Points.
	°F.	°F.	
May 31–June 13	60·9	49·1	294
June 14–June 28	56·5	44·5	164
June 29–July 12	60·1	45·4	43
July 13–July 26	53·4	44·8	281
July 27–Aug. 9	53·5	45·2	9
Aug. 10–Aug. 24	64·8	48·9	57
Aug. 25–Sept. 7	61·6	43·9	107
Sept. 8–Sept. 21	65·8	50·1	48
Sept. 22–Oct. 7	65·0	49·6	293
Oct. 8–Oct. 20	66·0	49·3	43
Oct. 21–Nov. 4	68·4	49·2	87
Nov. 5–Nov. 19	75·3	54·4	4

TABLE 9.—Showing the average mineral content of the herbage obtained from the different frequencies of cutting. Seasons 1927 and 1928. Expressed as percentages of dry matter.

—	Season 1927.		Season 1928.					
	CaO.	P_2O_5.	CaO.	P_2O_5.	K_2O.	Na_2O.	Cl.	SiO_2 Free Ash.
Series 1 ..	2·05	0·57	2·26	0·48	1·81	0·42	0·76	8·55
,, 2 ..	1·73	0·56	1·98	0·46	1·73	0·35	0·68	7·55
,, 3 ..	1·99	0·45	2·12	0·38	1·57	0·41	0·56	7·58
,, 4 ..	1·83	0·34	2·52	0·36	1·49	0·46	0·48	8·07
,, 5 ..	1·44	0·23	2·03	0·27	1·33	0·51	0·60	6·80

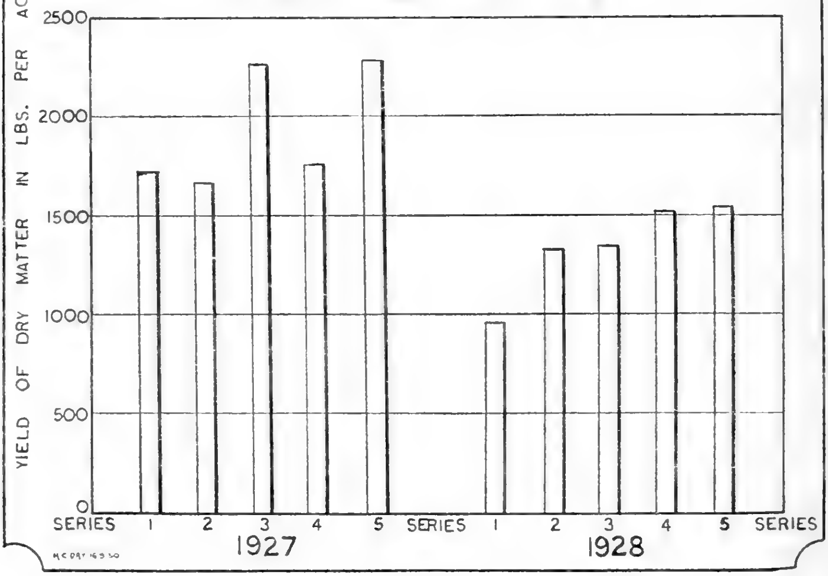
TABLE 10.—Showing the mineral content of the successive forthightly cuts in 1927 and 1928. Expressed as percentages of dry matter.

—	Season 1927.		Season 1928.					
	CaO.	P_2O_5.	CaO.	P_2O_5.	K_2O.	Na_2O.	Cl.	SiO_2 Free Ash.
1st cut ..	2·04	0·54	2·32	0·47	2·08	0·51	0·62	8·79
2nd ,, ..	2·14	0·57	2.46	0·45	2·24	0·69	0·87	9·51
3rd ,, ..	1·68	0·59	1·93	0·37	1·66	0·22	0·77	8·59
4th ,, ..	1·92	0·53	2·35	0·45	1·69	0·39	0·71	8·47
5th ,, ..	2·03	0·50	2·50	0·53	1·84	0·43	0·76	8·95
6th ,, ..	2·08	0·57	2·38	0·54	1·69	0·39	0·70	8·40
7th ,, ..	1·73	0·67	2·27	0·58	2·13	0·35	0·86	9·06
8th ,, ..	1·93	0·69	2·17	0·55	2·04	0·38	0·87	8·27
9th ,, ..	2·91	0·46	2·17	0·49	1·42	0·40	0·65	7·60
10th ,, ..	..	..	2·06	0·40	1·27	0·39	0·78	7·84

TABLE 11.—Showing the average percentage on dry matter of ether extract, crude protein, crude fibre and nitrogen-free extractives in the herbage from the five series, together with the approximate caloric values.

—	Ether Extract.		Crude Protein.		Crude Fibre.		N-free Extractives.		Caloric Values Calc.	
	1927.	1928.	1927.	1928.	1927.	1928.	1927.	1928.	1927.	1928.
Series 1. Mean of 10 cuts	2·10	1·78	14·56	15·38	18·84	16·92	55·20	50·41	287·4	270·3
Series 2. Mean of 5 cuts	2·28	2·12	14·00	13·63	23·43	20·67	51·03	52·10	269·2	271·4
Series 3. Mean of 3 cuts	2·40	1·64	10·56	11·63	25·33	23·53	53·41	51·33	265·5	258·4
Series 4. Mean of 2 cuts	2·05	1·44	8·56	10·56	25·18	27·73	56·37	49·25	267·9	245·0
Series 5. One cut ..	2·02	1·35	5·00	8·19	29·93	30·04	55·37	48·29	249·6	231·0

FIG. 1 SHOWING THE TOTAL YIELD OF PASTURE EXPRESSED AS DRY MATTER UNDER FIVE DIFFERENT SYSTEMS OF CUTTING SEASONS 1927 AND 1928



SHOWING THE YIELDS IN LBS. DRY MATTER PER ACRE FROM THE FORTNIGHTLY CUTS DURING THE SEASON 1928, TOGETHER WITH THE RAINFALL IN POINTS FOR THE CORRESPONDING PERIODS

FIG. 2

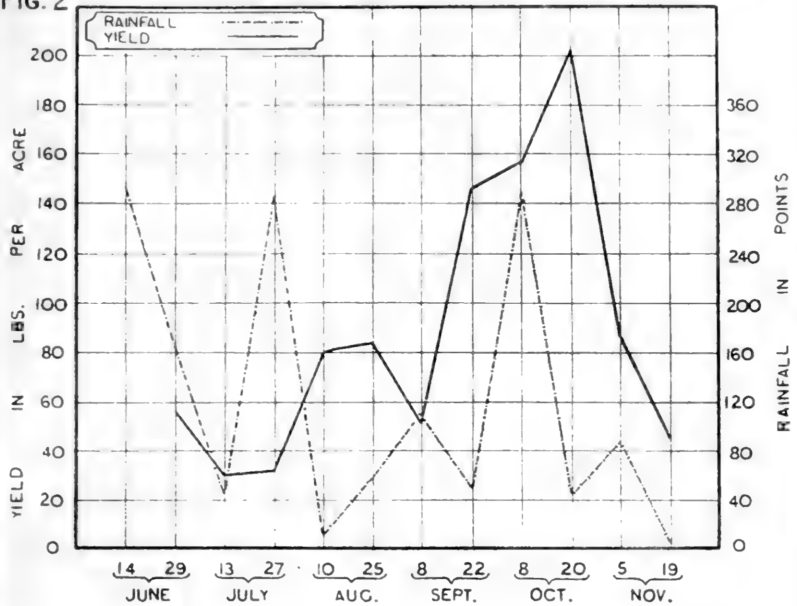
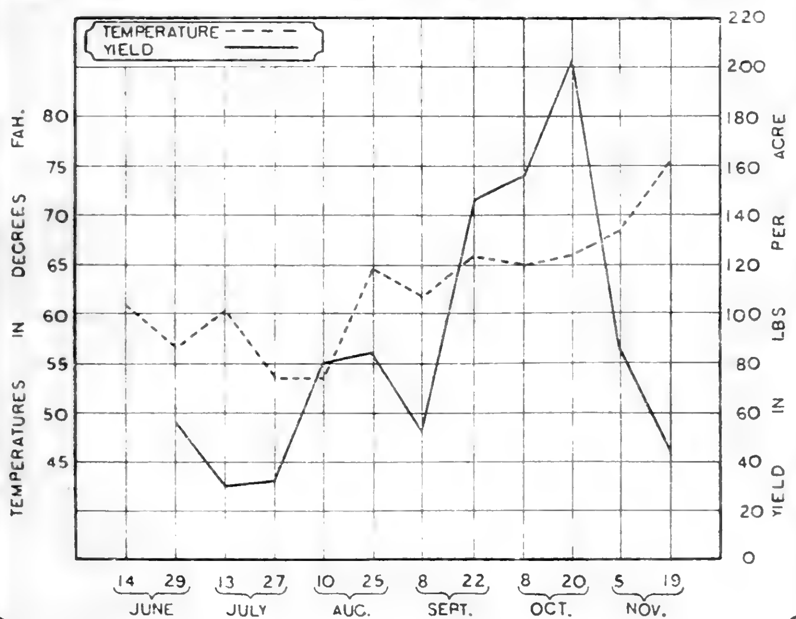
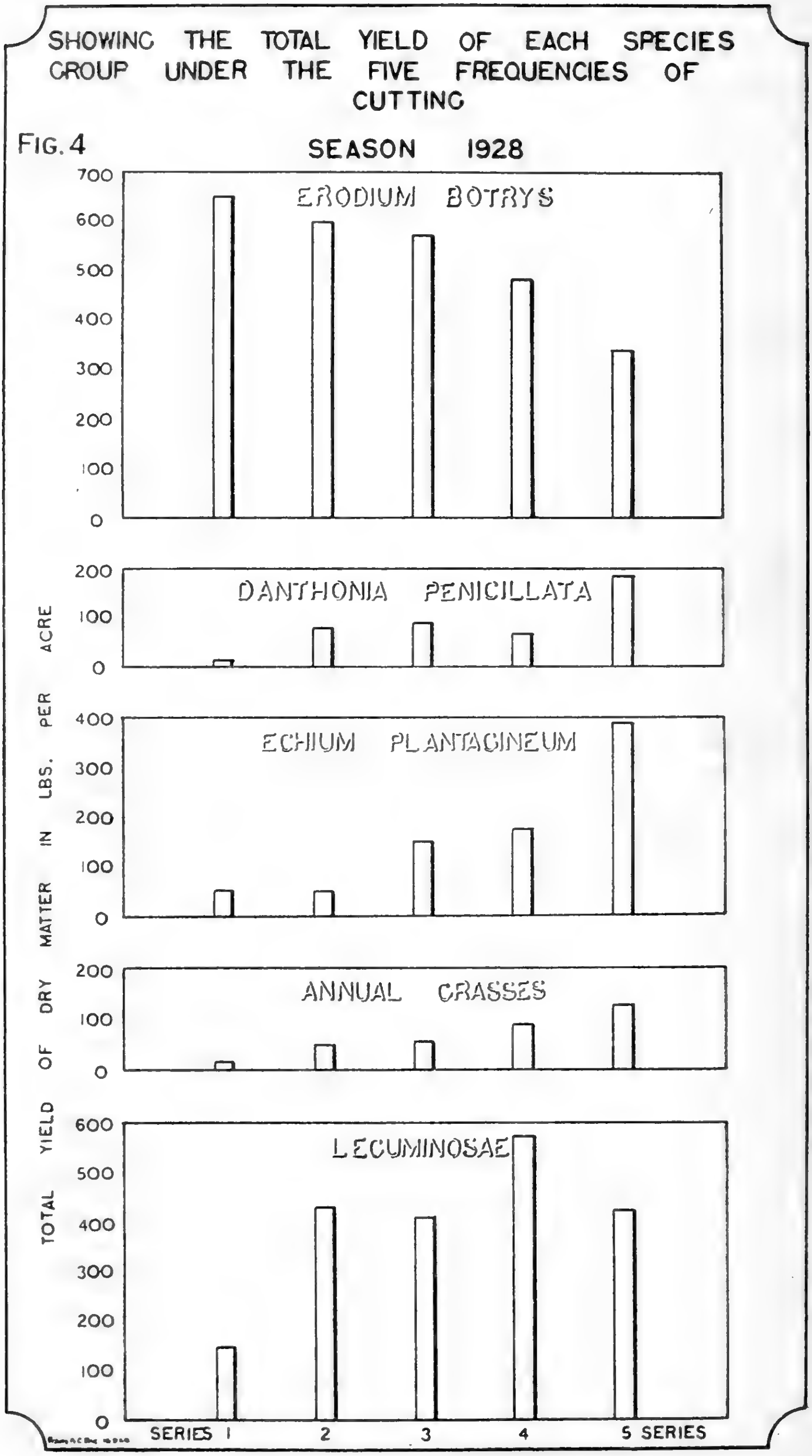


FIG. 3

SHOWING THE YIELDS IN LBS. DRY MATTER PER ACRE FROM THE FORTNIGHTLY CUTS DURING THE SEASON 1928, TOGETHER WITH THE MEAN DAILY MAXIMUM TEMPERATURE FOR THE CORRESPONDING PERIODS

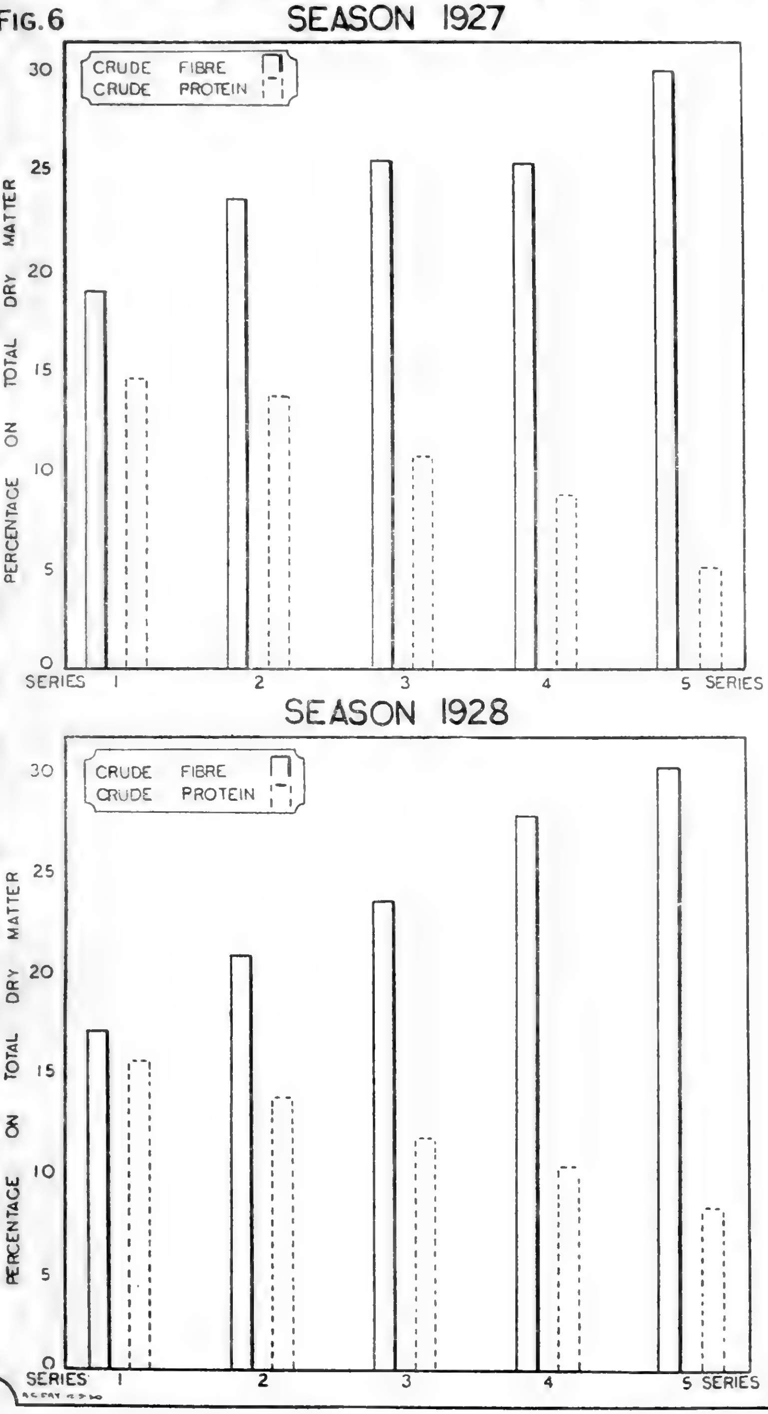




SHOWING THE TOTAL YIELD OF EACH SPECIES GROUP UNDER THE FIVE FREQUENCIES OF CUTTING
FIG. 4
SEASON 1928
ERODIUM BOTRYS
DANTHONIA PENICILLATA
ECHIUM PLANTAGINEUM
ANNUAL GRASSES
LEGUMINOSAE
TOTAL YIELD OF DRY MATTER IN LBS. PER ACRE
0
100
200
300
400
500
600
700
SERIES 1
2
3
4
5 SERIES

SHOWING THE PERCENTAGE OF CRUDE FIBRE & CRUDE PROTEIN IN THE HERBAGE UNDER THE DIFFERENT FREQUENCIES OF CUTTING

FIG. 6

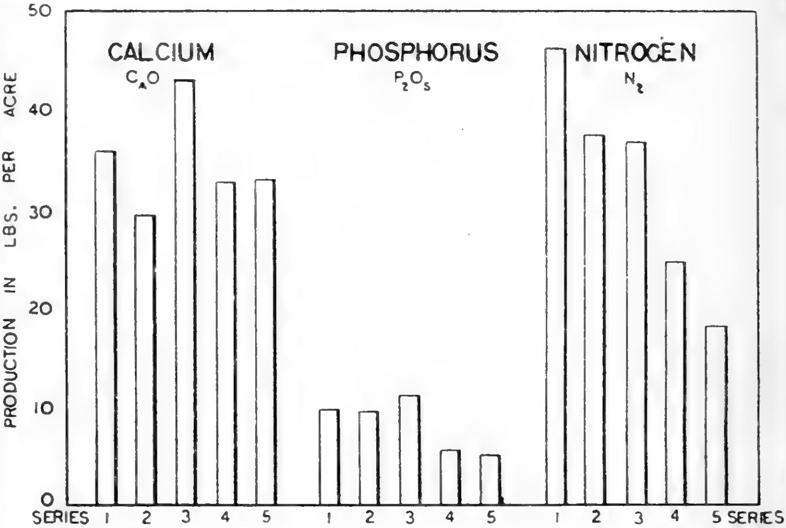


GRAPH SHOWING

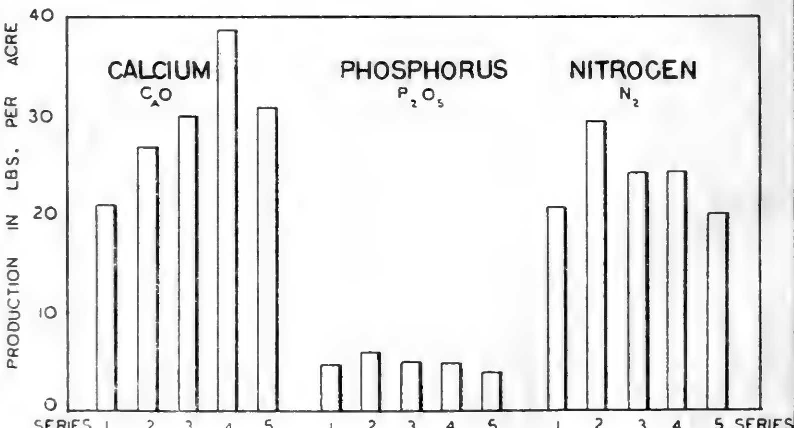
THE PRODUCTION OF CaO, P_2O_5 & N_2 IN LBS. PER ACRE UNDER THE DIFFERENT FREQUENCIES OF CUTTING

SEASON 1927

FIG. 5



SEASON 1928



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COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

BLACK DISEASE

A Short Description of its Nature and Means of Prevention

By
A. W. TURNER, D.V.Sc.

MELBOURNE, 1931

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CONTENTS.

Black Disease.

A Short Description of its Nature and Means of Prevention.

By Dr. A. W. Turner, Division of Animal Health, Council for Scientific and Industrial Research.

1. What is Black Disease?

By this term is meant a special disease of sheep*, with very definite characters, which should not be applied as merely a convenient general term to cover any cases of death among sheep. It is called scientifically, as well as in the Victorian Stock Diseases Act, infectious necrotic hepatitis.

The disease has been known in New South Wales for at least 60 years, in Victoria for a slightly less time, and in Tasmania for about 25 years; and there is no doubt that it has been and is still spreading. An estimate made by responsible officers of the Department of Agriculture in New South Wales just before the fall in prices placed the annual loss due to the ravages of Black Disease in that State alone at £1,000,000, so that it is of very great economic significance to Australia.

Under the law of the State of Victoria, every owner suspecting that losses occurring amongst his sheep are due to Black Disease is compelled, for the protection of himself and others, to notify the Chief Veterinary Officer immediately, failure to do so entailing a penalty of not more than £100. It is, therefore, extremely important that owners should know when to suspect the presence of the disease, and what steps to take to confirm their suspicions. Such action becomes all the more desirable when it is realized that Black Disease is a *preventible disease,* and that means have been discovered by scientists which, if thoroughly applied, should result in the total elimination of this serious disease from Australia.

2. When to Suspect the Disease in a Flock.

Black Disease affects rams, ewes, and wethers alike, and all ages from weaners onwards, so that it need not be confused with Pregnancy Paralysis (Twin Lamb Disease), which, of course, affects only ewes in lamb. It occurs mostly between the months of December and June, being at its worst usually in February, March, and April; for this reason, heavy losses during winter and spring are not likely to be due to Black Disease. Affected animals are nearly always in prime condition, at any rate, never in really poor condition; so that some other cause must be looked for when large numbers of poorly-conditioned sheep, or sheep that have been scouring, are lost, e.g., parasites or malnutrition.

Sheep affected with Black Disease die so suddenly and are noticeably ill for such a short time that it is rare to pick them out before death; the usual thing is to find fresh carcasses each day, while the rest of the flock is apparently healthy and in good condition. When animals are

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* It may be mentioned in passing that the same disease may occasionally affect cattle.

reported to have been seen standing or lying about ill for a day or two before dying, Black Disease may be discarded as a possibility, even in affected districts; in such cases acute fluke disease is to be suspected.

It is often possible to distinguish animals that are in the last stages of the disease by moving the flock around by means of a good dog. Under these conditions, a sheep in an advanced stage, but showing no signs of the disease when resting quietly, and which would probably have died quietly during the night, will be seen lagging behind the rest of the flock, unable to keep up with them. On forcing it to move it will soon lie down on its brisket, the legs tucked under and the head outstretched, obviously out of breath. Within a short time, varying from a few minutes to an hour, the animal will quietly die. There is never any evidence of struggling before death.

3. When to Suspect the Disease in Dead Animals.

In diagnosing the disease in dead animals, everything depends upon the freshness of the carcass. When carcasses are only a few hours old it becomes extremely difficult, even for the scientist with his laboratory facilities, to be sure of the presence or absence of Black Disease. For this reason it is necessary to forward specimens to the laboratory, if possible, only from sheep known to be dead less than an hour, or, better still, from sheep seen to die and examined immediately.

From the owner's point of view, there are several signs in carcasses that may be taken as good evidence of the presence of Black Disease.

The animals are in good condition. There is often a little pale to reddish jelly-like material under the skin, especially near the brisket. When the belly cavity is opened up, a cupful or two of clear to blood-stained fluid is found (colour of this and other fluids depending upon the freshness of the carcass). The animal being in good condition, a good supply of caul and kidney fat will be in evidence.

The liver will be found to be dark red and full of blood, the gall bladder full of bright green bile.

Upon either surface and any of the lobes or divisions of the liver one or more so-called "necrotic areas" are nearly always found. These vary in size from an area the size of threepence to one as large as half-a-crown; are often irregular in shape, with clear-cut edges; and are a pale yellowish colour, contrasting sharply with the dark congested liver surrounding them. If these yellowish patches are cut into, they will be seen to extend into the substance of the liver for some distance. Besides the yellowish patches, very dark reddish patches may also be present.

If the chest cavity is now opened, either by cutting through the ribs near the brisket, or by cutting through the diaphragm (the fleshy partition between the belly and chest cavities), a certain amount of clear to reddish fluid will be found. The most important chest sign, however, is found in the heart. If one examines a normal sheep's heart when slaughtering, one will notice that it is contained in a thin transparent bag that fits it tightly. In a sheep dead from Black Disease, however, this bag (pericardium) is separated from the heart by a certain amount, up to as much as half a cupful, of clear, often jelly-like, material.

It follows from the above that the presence of yellowish solid patches in the liver, and fluid or jelly-like material round the heart of sheep in good condition, dying suddenly without much in the way of symptoms, especially during the first three or four months of the year, will give very good grounds for suspecting the presence of Black Disease in a flock.

But suspicion can be turned into certainty only by means of laboratory examination of absolutely fresh, preserved specimens. Specimens should consist preferably of the whole of the internal organs, including heart and lungs (avoid pricking the heart sac and so spilling the fluid), placed in a kerosene or petrol tin, covered with weak formalin (one cupful to 2 gallons of water), and then soldered down. The tin should then be forwarded to the nearest local laboratory. Where it is not possible to send all the organs, the liver only may be sent, preserved as before, in a half petrol tin or even in a 7-lb. treacle tin, though in the latter case the liver sets in a twisted position, which makes further examination more difficult. At the laboratory, the organs are examined for the presence of the germ that causes the disease.

4. Recent Research on Black Disease by the Council for Scientific and Industrial Research.

A painstaking and thorough investigation into the nature and prevention of Black Disease, extending over a period of three years, and partly financed by the graziers' own money (The Pastoralists Research Trust) has just been concluded by the Council for Scientific and Industrial Research, aided by the valuable co-operation of the State Departments concerned, i.e., those in Tasmania, Victoria, and New South Wales. Stripped of technicalities and the scientific background, the following results have been obtained:—

The germ that causes the disease has been fully studied, and, as a result, an effective, though not costly, vaccine that will protect sheep against reasonable doses of the germ's poison or toxin has been developed. In addition, the suspicion, first put forward by the late Dr. Dodd, of the Sydney University Veterinary School, that the germ was enabled to attack the sheep's liver only because of injury by young liver flukes, has been definitely and amply proven. Since Black Disease exists only in fluky pastures, owners must expect to find that not all deaths may be due to it; a certain number may be due to acute fluke invasion of the liver. From this research have come the following recommendations to the pastoral industry:—

1. Absolutely eliminate liver fluke from the flocks of Australia, and so automatically get rid of Black Disease.

2. If this ideal cannot be reached, as in a great area of the fluke-infested country, do what you can against fluke; but, to make up for this deficiency and lessen the loopholes, have your sheep vaccinated or inoculated against the germ that joins forces with the fluke to produce the disease.

5. How to Prevent Black Disease.

As pointed out above, this entails—

1. fluke eradication;
2. vaccination,

to which must be added,

3. disposal of carcasses.

It is not proposed to tire readers with the reasons for the following recommendations, which are based on exhaustive scientific research. Any one wishing to know the reasons and wanting fuller details is referred to Bulletins 46 and 43 and Pamphlet 5 of the Council for Scientific and Industrial Research, as well as to the publications of the local State Departments of Agriculture and Stock. Stated briefly, the recommendations are as follow:—

1. *Fluke Eradication.*

(*a*) Drain pastures, especially marshy or boggy patches, wherever possible, and clean up the edges of irrigation channels, creeks, or springs, removing weeds and other vegetation.

(*b*) Treat other marshy or boggy patches, edges of watercourses, &c., with powdered bluestone (sulphate of copper) at the rate of 30 lb. to the acre of treated pasture. The cost of bluestone is about 12s. 6d. per acre. It is best mixed with four parts of clean dry sand to allow of broadcasting, or may be dissolved and sprayed if desired. Small bags of bluestone crystals may be placed in running streams or dragged through stagnant water to colour them faintly. The time for bluestoning is before the end of December and the end of June.

(*c*) Drench sheep with a mixture of one part of carbon tetrachloride and four parts of liquid paraffin (Dr. Seddon's method), giving 5 cc. of the mixture (cost about 1s. 10d. per 100 sheep), or, if preferred, give capsules containing 1 cc. of the pure drug (cost about 6s. per 100 sheep).

The times for treatment of sheep depend on how many treatments can be given, three being best. If three, treat at end of April, middle of June, and end of July; if two, middle of May and end of July; if one, middle of June.

2. *Vaccination of all Exposed Sheep during the Months of October and November.*

This is best carried out by the Stock Departments, and costs, for the two necessary treatments, about 2d. per sheep, depending upon the State and the number of sheep.

The vaccine developed by the writer has been found to be effective in reducing considerably the number of deaths from Black Disease. It is perfectly harmless when used as directed by experienced officers, and cannot possibly give rise to deaths due to vaccinating. But it will protect only against the germ of Black Disease, and, of course, has no action whatever on liver fluke. It follows that sheep vaccinated against Black Disease may still die of heavy doses of fluke or of other diseases, so that owners should always endeavour to send the specimens described above to the laboratory from any dead vaccinated sheep, on the chance that they are being attacked by another disease.

Even as regards Black Disease, it must be remembered that there is a limit to the degree of protection given by two doses, and that, if the liver is repeatedly attacked by large numbers of flukes over a short period, the protective properties of the blood due to vaccination may give out, and the germ of Black Disease may still be enabled to grow.

Since the disease begins usually about January or February, vaccination should be carried out in ample time to allow of the full protective properties of the blood being developed. It is, therefore, recommended to have this done during the months of October and November, or November and December.

All vaccines lower the resistance of the body to the corresponding disease for a short time after administration. For this reason, and also because the full protection is not obtained until about a fortnight after the second dose, vaccination during an outbreak should be embarked upon only with the distinct understanding that the best results are not to be expected and that, in fact, losses may be temporarily increased for a few days.

3. *Disposal of all Carcasses.*

These contaminate the soil further with the germ. They should be burnt as soon as the carcass is found, on the spot, if possible; or, if removed to a more convenient spot, the surrounding surface soil should also be removed and burnt. Where burning is impracticable, the next best thing is to bury carcasses and soil deeply in a small, unused, fenced-off paddock.

6. Conclusions.

If the above recommendations were all thoroughly applied, Black Disease would be wiped out of Australia.

The ideal method is to carry them all out. Where this is possible and losses have been heavy, it will pay to do so, although it appears to be a heavy routine. Apart from labour and the trouble of handling, the cost of drenching and vaccinating a hundred sheep is about £1 2s. 2d. per year, i.e., a little over 2½d. per sheep. The cost of bluestoning snail carrying depends entirely upon the property.

Where conditions make the full programme impracticable, changes must be made. If it is possible to make a thorough attack upon the fluke, by drenching and bluestoning, concentrate upon this; and, as long as results remain good, vaccinating may not be necessary. Many properties in Victoria and New South Wales have found this effective. But where the full anti-fluke treatment cannot be given, or where experience has shown that little result follows its application, the pastoralist is well advised to vaccinate.

On very bad properties, particularly where bluestoning is difficult to carry out thoroughly (irrigation districts properties sharing a common marsh or stream properties richly supplied with springs), experience has shown that three vaccinations may almost eliminate the disease, although, of course, some losses from acute fluke may continue if the pasture be heavily contaminated with that parasite.

Black Disease Calendar.

There are thus two programmes, the full one and the partial:—

Full.	*Partial.*
January.	January.
February.	February.
March.	March.
April (end)—Drenching.	April.
May.	May.
June (middle)—Drenching.	June (middle)—Drenching.
(end)—Bluestoning.	July.
July (end)—Drenching.	August.
August.	September.
September.	October—1st vaccination.
October—1st vaccination.	November—2nd vaccination.
November—2nd vaccination.	December——Bluestoning.
December (end)—Bluestoning.	

In conclusion, always get into touch with your State Stock Department, whose officers are always eager to assist, both to find out whether Black Disease is responsible for your losses, and also to help you in preventing it.

Scientific Investigations.

Those who are interested in the details of this work, which has been pursued for many years in Australia on the above subject, are referred to Bulletin 46 issued by the Council for Scientific and Industrial Research, copies of which may be obtained from The Secretary, C.S.I.R., 314 Albert-street, East Melbourne, C.2.

The Australian investigators (in addition to the writer) whose researches have brought the knowledge of Black Disease to its present state include Gilruth, Dodd, Albiston, Edgar, and Oxer; prominent in the study of liver fluke in Australia have been Seddon, Clunies Ross, and McKay.

Fig. 1.—A sheep that had previously shown no signs of illness is seen lagging behind the flock on being chased by dogs.

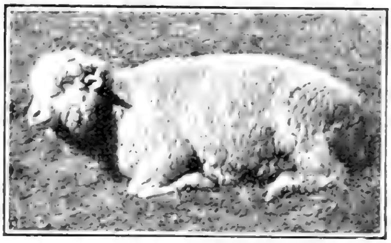

Fig. 2.—A sheep ill with black disease. Note the extended head and the dilated nostrils.

Fig. 3.—In sheep dead from black disease the skin quickly becomes black and the wool easily pulls out. A man is seen plucking the wool from a carcass. The dark skin is plainly noticeable.

Fig. 4.—A bad type of irrigation channel in the Kerang district, showing the ill-defined banks and the overgrowth with weeds. Fluke-carrying snails (*Limnea brazieri*) were found in abundance here.

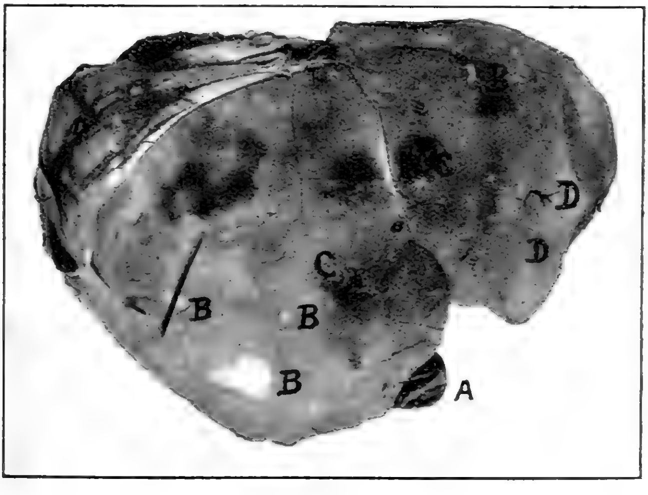

Fig. 5.—Liver of a sheep dead from black disease, showing at A the gall bladder, at B the so-called "necrotic areas" (one cut into), and at C dark reddish patches.

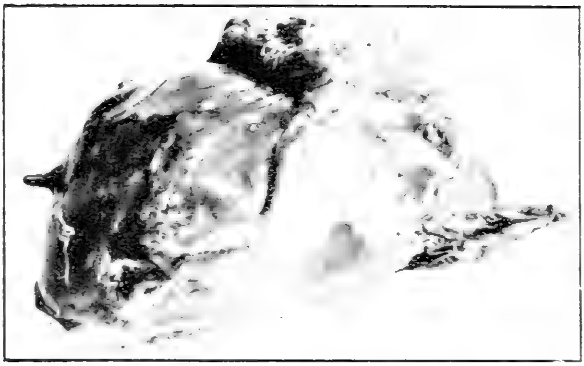

Fig. 6.—Heart of a sheep dead from black disease, showing the heart-sac filled with fluid.

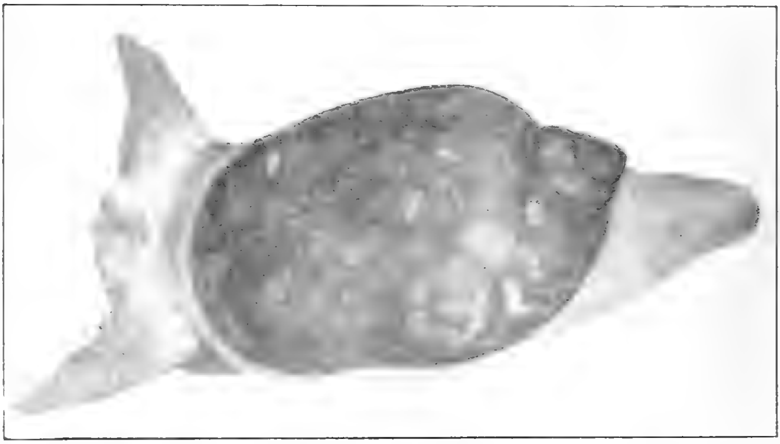

Fig. 7.—A greatly enlarged picture of the water snail that causes liver fluke, and is therefore concerned in black disease. Note the ear-shaped "feelers," and the fact that, if the shell is held mouth downwards with the point away from one, the twist of the shell is from left to right. The actual length of the snail is from a quarter to half an inch.

(Photograph kindly taken by Mr. E. Murray Pullar, M.V.Sc.)

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PAMPHLET No. 20.

COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

The Identification of Wood by Chemical Means.—Part I.

(Division of Forest Products.—Technical Paper No. 1)

By

H. E. DADSWELL, M.Sc.

MELBOURNE, 1931

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H. J. Green, Government Printer, Melbourne

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Council for Scientific and Industrial Research

314 Albert Street,
East Melbourne,
Victoria

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CONTENTS.

FOREWORD.

The identification of the species from which commercial timbers are derived is of the utmost economic importance. The problem is by no means an easy one except in some special cases. Timbers from related species are frequently so closely alike in physical structure that a study of macroscopic or microscopic features will not do more than place the timber in its genus, or in a group of species under a genus.

This is particularly so with the hardwoods of Australia. The Eucalypts can be divided without much difficulty into groups, but closer differentiation is frequently a matter of intelligent guesswork based on a close acquaintance with appearances, or it may depend upon the balancing of a number of factors with the probabilities pointing with more or less certainty to one or more species.

This position is most unsatisfactory and often leads to great difficulty, for two timbers very closely similar in physical appearance often have very different properties. The substitution of one of these for the other may have, and frequently has had, serious consequences. For example, jarrah and karri are so much alike that even experts can be deceived, yet jarrah is a durable timber and has considerable resistance to attacks of rot and white ants, while karri is quite unsuitable, unless treated with preservatives, for any use in contact with the ground.

Many cases of doubtful identity, some of them involving questions of considerable economic loss, have been brought to the notice of this Division.

A section of wood technology for the close study of the physical structure of Australian timbers was established in conjunction with the Commonwealth Bureau of Forestry in 1929. It is hoped that this will give important information which will assist in the work of identification.

Several cases like that of jarrah and karri indicated that such species had definite chemical differences, and this idea led to a study of chemical methods of identification.

These have been successful in a number of instances, and Technical Paper No. 1 is the first of a series to be published dealing with this method.

I. H. BOAS,

Chief, Division of Forest Products.

19th June, 1931.

SUMMARY.

1. The value of chemical methods for the identification of woods that are structurally similar has been investigated and demonstrated.

2. The use of the aqueous or alcoholic extracts in colour tests with certain reagents has been shown to have limited application on account of the wide variation in the amount of extractives present in different samples of the one species.

3. Karri (*E. diversicolor*) and jarrah (*E. marginata*) have been separated by chemical means, namely, on the basis of differences in the cellulose content and in the alkalinity of the ash.

4. Tallowwood (*E. microcorys*), blackbutt (*E. pilularis*) and white mahogany (*E. acmenioides, E. carnea,* and *E. umbra*) have been separated on the basis of the alkalinity of ash together with the behaviour of alcoholic extracts on dilution with water.

5. The members of the Ironbark group, namely, *E. paniculata, E. sideroxylon, E. siderophloia, E. crebra,* together with the related grey gums (*E. propinqua* and *E. punctata* have been, and are being, investigated, and to date certain separations have been accomplished.

6. A simple test has been developed for the separation of red box (*E. polyanthemos*) and red gum (*E. rostrata*) and for confirmation is being applied to further samples from different localities.

7. The application of these methods is being extended to other pairs and groups of woods difficult to identify by ordinary methods.

The Identification of Wood by Chemical Means.—Part I.*†

1. Introduction.

The structure of wood from different botanical species is variable within certain limits and the macroscopic and microscopic examination of any particular sample, based on the knowledge of the possible structural variations, enables the wood technologist* to classify it with respect to genus, and in many cases with respect to species also. However, the methods of identification available to the wood technologist are not perfect, and at times they have a limited application, as, for example, when applied to samples of wood from closely related species of the same genus. In such cases, it is often found that even detailed microscopic examination of authentic samples does not reveal structural differences of value for the development of a key for identification. In Australia, a large proportion of the hardwoods cut for marketing belong to the same genus, *Eucalyptus,* the known species of which number over 300. Such a condition renders definite identification necessary, but under present conditions, the technologist can only hope to place an unknown sample of wood into one of a number of definite groups, and cannot with certainty go further. The economic importance of definite identification in this and other similar instances is very considerable, and it has been considered that, in cases where no structural differences are apparent, some constant differences in chemical composition may be found. Such, if detectable by easy and rapid methods of analysis, should prove invaluable as an aid in wood identification.

In any such investigation into the chemical composition of two or more closely related species, two points must be borne in mind—(i) the possible variation in composition within a species, and (ii) the need for the examination of authentic samples. The former may be overcome by the examination of a large number of samples collected from various districts representing the known distribution of the species, while for the latter, extreme care must be taken to examine only those samples that are supported by well authenticated botanical material. If these precautions are not taken, the results may prove valueless.

Differences in chemical composition may be investigated in two ways:—

1. By means of quantitative analysis.

2. By the development of simple qualitative tests based on slight differences in chemical composition.

A combination of both qualitative and quantitative analyses should prove the ideal—a simple qualitative test that would be an effective means of identification in most cases, followed by a quantitative determination where any doubt existed. Quantitative analyses following a standard procedure are likely to reveal some points of difference in the

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* Typescript received for publication 19th June, 1931.

† Throughout this paper the term "wood technologist" is used in the sense usually adopted by Forest Products Laboratories throughout the world, namely, one who classifies timbers by a visual examination of their structure.

chemical composition of a pair of closely related woods. It is possible, for example, that the cellulose content of such woods will not be similar. These determinations, however, although valuable when definite results are desired, take several days to complete. The test of most value to the technologist would be a simple qualitative test for which no great chemical knowledge is essential.

The purpose of the present investigation was, therefore, the development of suitable methods of chemical analysis by means of which woods that are structurally identical may be distinguished with some degree of certainty. It is not suggested that chemical methods will replace other methods now adopted by the wood technologist, but it is hoped that they will be of material assistance in the development of identification keys for groups which have hitherto proved a problem.

2. Previous Work.

Several wood technologists have developed and used certain simple qualitative tests as an aid to identification. R. Kanehira (1), for example, in his "Identification of Formosan Woods," mentions the use and value of chemical characters such as colour, flavone content, and fluorescence of extracts. In the development of his identification key, the so-called flavone test and the fluorescences of the extracts are used for distinguishing between closely related species.

For the flavone test, some of the alcoholic extract (5 to 10 cc.) from the wood sample is acidified with concentrated hydrochloric acid, and a few cc. of this mixture is placed in a test tube with a drop of mercury the size of a pea and a small amount of magnesium powder. As a result of the reduction which occurs, the solution develops a colour which is often intensified on standing. Comparative determinations of flavone content prove difficult and only three grades of colour are distinguished—(i) strongly coloured, (ii) moderately coloured, (iii) faintly coloured. The actual colours of the original alcoholic extract and the resulting so-called anthocynanin solution are both recorded. Tests of this nature were carried out with a large number of Formosan woods. The fluorescence is observed in the cold water extracts of the chips (two weeks extraction). If not strong it is observed by means of a small camera box. It is often intensified by the addition of ammonia. However, Kanehira admits that this is an uncertain criterion.

Welch, of the Sydney Technological Museum, has also tried some simple chemical tests for distinguishing members of different groups of the genus *Eucalyptus*(2). He used both aqueous and alcoholic extracts from wood shavings and tested these extracts with such reagents as ferric chloride, caustic potash, lime water, ferrous sulphate, &c. The colours of the resulting solutions and precipitates were noted. He states that such tests should be used with caution on account of the variations in behaviour found in different samples of wood from the one species, but he also suggests that such methods of identification are in many cases far more accurate than the ordinary superficial examination of a wood sample. Unfortunately, in his work no record is made of the exact colours of the precipitates and solution, and only general comparisons are given. The value of such results is far greater if the colours are specified according to some standard colour scheme. The colour obtained will depend entirely on the amount and nature of the extractives which are removed from the wood. It is also possible to obtain a number of variations of the one colour when the extracts from different samples of the one species are tested. Hence, for purposes of identification, it is useless to say that the colour of the extract from one sample of a species after treatment with a chemical reagent is darker or lighter, as the case may be, than an extract from a sample of a different species treated in the same way. It is, therefore, essential that, prior to their adoption, simple chemical tests based on colour changes should be examined very carefully, using a large number of samples.

One other simple test is often employed by technologists. This is the burning splinter test(3). Splinters, approximately half match size, are taken from the wood samples under examination and burnt. Observations are then made on the resulting ash, if any. This test has proved more reliable than most others, although doubts have often been expressed as to its practical value. It will be discussed later.

Results of quantitative analyses of North American and European wood samples have been used for distinguishing between different genera, and many of these have been published(4). In addition, chemical analyses have been employed in distinguishing between the sap wood and heart wood of the same tree(5), and also between the summerwood and springwood(6).

Comparative analyses have also been made of "compression" wood and normal wood from the same annual rings, and of tough and brash samples from the same tree, in order to study the relationship between chemical composition and physical characteristics(7).

No attempts have been made, however, to compare the results of analyses of a number of closely related species from the same genus.

3. Discussion of Problem.

In planning the present investigation, it has been considered that woods from the closely related species, i.e., from species placed by the technologist in the same group, will show some differences in chemical composition of such a nature that they will be revealed by simple tests. The great difficulty lies in the finding of a suitable test which will clearly mark the differences. The present standard methods of wood analysis(4) are such that they may or may not reveal any differences. For example, the percentage of extractives, as determined by the extraction of the wood sample with solvents such as water, alcohol, or ether, has been found to be very similar for different species. This, however, does not mean that the constitution of the extractives is the same in each case. Again, although the percentage of inorganic material as revealed by the ash determination has not proved of value for identification purposes, the study of the constituents of the ash may lead to interesting possibilities. On the other hand, the determination, according to a standard procedure, of the amount of the cell wall constituent present in different species—or in other words the cellulose—has been proved to be of decided importance.

In the case of the genus *Eucalyptus*, confusion often arises as to the botanical identity of certain species. For this reason, special care must be taken to work with samples whose identity has been definitely established by means of examination of the botanical material to which they belong. In a preliminary investigation, it is necessary to confine the study to that of heartwood samples only, for it has been shown(5) that, especially as regards the extractive content, there are chemical differences between the heartwood and sapwood from the same tree, and erroneous conclusions may be drawn if sapwood or heartwood are taken indiscriminately.

The first timbers investigated belonged to the Ironbark group and consisted of the following:—

E. paniculata (grey ironbark).
E. sideroxylon (red ironbark).
E. crebra (narrow leaved ironbark).
E. siderophloia (broad leaved or red ironbark).

Together with the above species, samples of grey gum (*E. propinqua* and *E. punctata*) were examined, as it is at times difficult to separate the wood of these two species from that of the Ironbarks. Welch (8) reported the results of some simple tests in the study of all these timbers, but did not record any test which proved effective as a means of identification nor the number of samples examined for each species.

The wood from the two Western Australian species, *E. marginata* (jarrah) and *E. diversicolor* (karri) is very similar in macroscopic and microscopic features. It is claimed(9) that normal specimens are easily identified, but that some occur which it is quite impossible to identify by ordinary means. It is after delivery to the consumer that danger of mixing arises. Both these timbers are important from the commercial point of view and therefore were selected for examination in order to find, if possible, some suitable means of separation. Another pair of woods, namely, *E. microcorys* (tallowwood) and *E. pilularis* (blackbutt) are often confused with one another and also with a timber called white mahogany.*

This latter timber is cut from three very closely related species, namely, *E. acmenioides, E. umbra,* and *E. carnea.* The wood from these three botanical species is identical in structure, and in the work now being reported, no distinction between them has been made. It is recognised that the three timbers tallowwood, blackbutt, and white mahogany can in many cases be distinguished one from the other, but there are times when this is impossible and so the group has been included in this preliminary study. Two other Eucalypts, which present a similar difficulty, namely, *E. polyanthemos* (red box) and *E. rostrata* (red gum), have also been investigated.

4. Tests with Aqueous and Alcoholic Extracts.

1. The first experiments aimed at the possibility of using the aqueous and alcoholic extracts from different species, and comparing the results of treating these with such reagents as ferric alum, ferrous sulphate, lime water, ferric chloride, caustic potash, and lead acetate. The extracts used were those obtained by the treatment of wood samples (80-100 mesh) according to the standard methods for the determination of alcohol and hot water soluble constituents. For the purpose of comparison, each aqueous extract was diluted to approximately 150 cc. and each alcoholic extract to approximately 30 cc. per gram of oven dry wood extracted. These extracts were treated with equal volumes of each of the above reagents, which were used at a concentration of 1%, and observations were made on the results. (Colours were compared by means of drops on a white spot plate.)

* White mahogany in New South Wales, yellow stringybark in Queensland. In this paper the common name adhered to will be white mahogany.

This procedure was applied to the woods of the Ironbark group on the one hand, and to karri and jarrah on the other. No striking differences in colour that proved of value as aids to identification were obtained. This was due, undoubtedly, to the presence of the same tannins in the extracts from each species, as proved by the deep blue precipitate and colour given on the addition of iron salts.

Using a standard colour chart, certain differences were noted when extracts from the different species of Ironbarks were tested, but these differences were in depth of colour only and depended entirely on the amount of extractives removed from the sample by the solvent. As this amount varied considerably even with different samples of the one species, it has been concluded that these tests are not helpful in the separation of such a large group as the Ironbarks and the two related grey gums, or even in the separation of jarrah and karri. Although disappointing, the results obtained made clear the following points:—

(1) Considerable variation must be expected even with different samples of the one species.

(2) As a result of (1), caution must be exercised in the development of tests based on the use of aqueous or alcoholic extracts.

(3) A previous knowledge of the chemical composition as obtained by quantitative analysis is of great assistance in the development of any simple test.

5. Identification of Karri and Jarrah.

(i) *Cellulose Determinations.*—As stated above, the tests based on an examination of aqueous and alcoholic extracts from these two species proved unsatisfactory. In order to obtain further information, authentic samples of both were therefore analysed according to the standard procedure(4) employed at the U.S. Forest Products Laboratory, Madison. In each case, the sawdust passing through an 80 mesh and remaining on a 100 mesh sieve was used for analysis. The complete results of these analyses will be reported in a later publication. The most important results from the point of view of separation were obtained by means of the cellulose determination. This led to the analysis of a larger number of authentic samples for cellulose only. The samples were obtained from Western Australia—to which State the species are indigenous—and were collected in different districts. In all, 34 samples of jarrah and 17 of karri were analysed for cellulose content. The cellulose percentage on the oven dry basis was found to vary from a minimum of 38.4 to a maximum of 51.6 (average value 44.5) in the case of jarrah, while in the case of karri, the variation was from 53.0 to 62.7 (average value 59.0). It will be noted that there is no overlap in these figures, the highest value for jarrah being lower than the lowest for karri. The results show the value of this quantitative determination in the separation of these two species.

This determination, however, is not a simple operation and a knowledge of the technique is necessary. Further investigations were therefore carried out in order to develop a simpler method of separation.

(ii) *Burning Splinter Test.*—The burning splinter test has been previously applied to the separation of these species, but the value of such a test has not been definitely established. It has been claimed(9) that, in general, and provided sound heartwood is used, samples of karri burn to a definite white ash, while samples of jarrah do not burn readily, leave no ash, and give what is termed a carbon end. On the other hand, Campion (10) does not recommend this test and states that both timbers are capable of yielding either type of ash; that, in fact, under certain conditions (not mentioned), the same specimen can be induced to produce both types, and that results appear to be due to the size of the chip burnt and the amount of moisture it contains. Such contradictory statements are misleading and accordingly the value of the test was further investigated. Over 200 samples of jarrah drawn from different sources, and 150 of karri similarly obtained, were examined. In all cases the splinters from the karri samples burnt well, glowed for a long time, and formed a very definite white ash. The splinters from the jarrah samples did not burn well, did not glow, and in the majority of cases left no ash. In a few instances, a very fine black ash was left, but this could never be mistaken for the white ash left on burning karri. Neither the size of the splinter nor the moisture present had any apparent effect. Splinters from both woods were soaked for several days in water, and no changes in the results of burning were noted. Splinters from weathered jarrah and from jarrah sapwood did, however, burn to white ash. The amount of this ash and its colour depended on the condition of the sample, and whether it was badly weathered or not. These results have led to the conclusion that the burning splinter test is effective as a means of identification provided *sound heartwood* is always used, and the sample has not previously been treated with inorganic preservatives.

(iii) *Alkalinity of Ash.*—The work on the burning splinter test led to the development of a simple quantitative chemical test which has proved of great value. This involved the ashing of sawdust samples in an electric muffle furnace and an investigation of the alkalinity of the resulting ash. The following procedure was followed:—

Weighed samples of sawdust (5 to 6 grams) were ashed in a platinum dish and the percentage ash determined (calculated on oven dry basis). The ash was then treated in the platinum dish with a known amount of N/10 hydrochloric acid (5 to 10 cc. according to the amount of ash), the mixture warmed slightly, and then stirred with a glass rod until the reaction was complete. The resulting mixture was titrated with N/10 sodium hydroxide using phenolphthalein as indicator. From the results, the amount of N/10 acid required to neutralize the ash was obtained. The alkalinity of the ash was then calculated and recorded on the basis of one gram of the oven dry wood originally used.

This determination was applied to the available samples of jarrah and karri. The results of the determination of both percentage ash and alkalinity of ash are as follows:—

Name.	Number of individual samples tested.	Percentage ash by weight.*			Alkalinity of ash in c.c. N/10 acid per gm. O.D. wood.		
		Average.	Max.	Min.	Average.	Max.	Min.
Karri ..	29	0·30	0·86	0·12	0·63	1·57	0·33
Jarrah ..	58	0·14	0·49	0·04	0·06	0·16	0·00

* Calculated on the oven dry weight of the original wood.

The results show the value of the alkalinity of the ash as a means of distinguishing between jarrah and karri. The minimum value recorded for a karri sample is over twice the maximum recorded for a jarrah sample. The method has the advantage of being a simple determination and nothing is left to the personal judgment of the observer as in the burning splinter test.

Although in general the percentage ash of karri was greater than that of jarrah, there is too much overlap for this determination to be reliable. It has also been proved that even in this determination sound heartwood should always be used. Weathered samples of jarrah may show an alkalinity of ash well within the karri range.

The process of weathering definitely changes the chemical composition of those portions of the wood exposed, and this change is especially marked in the ash, although in one or two cases investigated there was little change in cellulose content. There seems to be no doubt that there is a definite connexion between the colour of the ash and the alkalinity. It was found by experiment that splinters of jarrah that had been soaked in a solution of sodium carbonate burnt to a white ash.

The results of these experiments with karri and jarrah show that the chemical methods of identification are very important, and that they are, in this instance, effective when other methods fail.

6. Identification of Tallowwood, Blackbutt, and White Mahogany.

(i) *Alkalinity of Ash.*—Authentic samples of the heartwood of these species were obtained from different localities covering the growing range of each species (coastal areas of N.S. Wales and Southern Queensland). Preliminary experiments and the results of quantitative analysis showed that the alkalinity of the ash was again a very important factor. The following results were obtained:—

Name.	Number of individual samples examined.	Percentage ash by weight.*			Alkalinity of ash in c.c. N/10 acid per gm. O.D. wood.		
		Average.	Max.	Min.	Average.	Max.	Min.
Tallowwood .. (*E. microcorys*)	26	0·27	0·56	0·11	0·42	1·18	0·19†
Blackbutt .. (*E. pilularis*)	34	0·16	0·51	0·05	0·05	0·15	0·00
White Mahogany (*E. acmenioides*) (*E. carnea*) (*E. umbra*)	32	0·09	0·18	0·02	0·02	0.10	0·00

* Calculated on the oven dry weight of the original wood.

† One exceptional sample of tallowwood showed alkalinity of ash as low as 0·06 c.c. per gram oven dry wood.

It will be noticed that the alkalinity of the ash from tallowwood samples is considerably higher than that from the other two species, with the exception of the abnormal case noted. These results were duplicated by the burning splinter test in which tallowwood samples burnt to a definite ash, white to greyish white in colour, while samples from the other species gave no ash but left a carbon tip. However, by these results it is only possible to separate tallowwood from the other two, and in one case this was not possible. Further tests were therefore considered desirable.

(ii) *Dilution of Alcoholic Extracts.*—It had been noted in the quantitative analysis of these woods that the material extracted from tallowwood by ether was of a waxy nature. This is in keeping with the well-known greasy appearance observed on freshly cut surfaces of this timber. The other species do not show such a decided greasiness and correspondingly the material extractable by ether is not of such a waxy nature. The ether soluble material isolated from tallowwood dissolved readily in alcohol and was thrown out of solution in the form of fine oily droplets by the addition of an equal volume of water. That from blackbutt, however, although soluble in alcohol, was not thrown down on the addition of water. As a result of these experiments, the following simple distinguishing test was developed for these timbers.

Approximately two grams of sawdust from the wood sample under examination are heated with 20 cc. alcohol for two minutes. The extract is allowed to cool to room temperature, filtered from sawdust, and a portion of it diluted with an equal volume of water. If the sample is tallowwood, a definite white turbidity is immediately formed, but if the sample is blackbutt the solution remains clear (after some time a precipitate may be thrown down).

Samples of white mahogany, when subjected to the above test, gave an immediate turbidity similar to that from tallowwood samples, with the difference, however, that after standing the turbidity changed to a fine white precipitate which could be removed by filtration, leaving a clear liquid. The turbidity obtained from tallowwood samples was not filtrable through qualitative filter paper. This test was shown to be reliable by the examination of all the available samples of each series (for numbers see above).

Even if the test left any doubt as to the distinction between tallowwood and white mahogany, reference to results from the alkalinity of ash determination would settle the question. Thus by the application of a simple quantitative determination and a simple qualitative test, it is possible to separate with certainty the three species investigated.

7. Investigation of the Ironbark Group.

Some interesting results were obtained when the alkalinity of the ash determination was applied to the members of this group (species examined listed on page 10.) Samples of *E. sideroxylon, E. propinqua,* and *E. punctata* all showed a low alkalinity of ash (less than 0.16 cc. N/10 acid per gram oven dry wood), samples of *E. paniculata* a high alkalinity of ash (above 0.78 cc. N/10 acid per gram oven dry wood for authentic samples examined), while samples of *E. siderophloia* and *E. crebra* gave an alkalinity of ash which was variable (for the former between 0.35 cc. and 0.05 cc., and for the latter between 0.90 cc. and 0.32 cc.). Larger numbers of authentic samples need to be examined. The above results cover only 10 to 15 samples of each species. The indications are, however, that a high alkalinity of ash is indicative of *E. paniculata* or *E. crebra,* while a low alkalinity of ash is representative of the other species. It has been found that the cellulose content of *E. paniculata* is uniformly higher than that of *E. crebra* (49.0 to 56.0 per cent. as compared with 35.4 to 46.3).

The dilution of the alcoholic extract test (as described for tallowwood and blackbutt) separates samples of *E. sideroxylon* which show an immediate turbidity with a tendency to fluorescence. Samples of *E. siderophloia*, *E. propinqua*, and *E. punctata* when subjected to the same test do not give this result. To date, no way of separating *E. siderophloia* from *E. propinqua*, and *E. crebra* from *E. siderophloia* has been found, but further experiments are in progress. The results, however, are extremely interesting in that it is possible (i) to distinguish between grey ironbark (*E. paniculata*) and grey gum (*E. propinqua* or *E. punctata*), two species often hard to identify, by means of the alkalinity of the ash determination, (ii) to separate *E. paniculata* and *E. crebra* on the basis of the cellulose determination, and (iii) to separate *E. sideroxylon* from the others by the alkalinity of ash and the dilution of the alcoholic extract.

8. Experiments with E. Polyanthemos (Red Box) and E. Rostrata (Red Gum).

Preliminary experiments with samples of these two species showed the possibility of developing a distinguishing test. This was based on a reaction of the alcoholic extract of the sawdust previously extracted with hot water. In this way, extracts were obtained of materials present which are insoluble in hot water. When 0.5 cc. of 1% caustic soda solution was added to about 5 cc. of these alcoholic extracts and the mixture warmed in a boiling water bath, a chocolate precipitate was formed immediately when samples of *E. rostrata* were tested, while with samples of *E. polyanthemos* a yellow precipitate was thrown down, leaving a supernatant liquor of a yellowish green colour with a tendency to fluorescence. This simple test has been applied to seven different samples of each species without any exceptions being found. It remains for further samples to be examined.

9. General Discussion.

It is considered that the value of chemical tests and analyses in the separation of woods of similar structure has been sufficiently demonstrated. It now remains to apply the above and other tests to numerous closely related pairs which the technologist has found difficult to separate. It is proposed to continue the study of the Ironbark group and also to investigate the following:—

- *E. marginata* (jarrah) and *E. resinifera* (red mahogany).
- *Araucaria Cunninghamii* (hoop pine) and *A. bidwilli* (bunya pine).
- *E. diversicolor* (karri) and *E. saligna* (blue gum).

As the work of the technologist on the identification of the members of the genus *Eucalyptus* develops, so further pairs or groups of timber closely related in structure will be discovered. Although these may possibly be separated by microscopic means, this method is often tedious and unreliable owing to the variation within a species. The development of suitable chemical methods in such cases is justified and desirable.

It is too early to claim that chemical methods will succeed in every case, but undoubtedly their use as a supplement to ordinary methods of identification will materially extend our ability to identify an unknown sample of wood with some certainty.

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Council for Scientific and Industrial Research

The Density of Australian Timbers
A Preliminary Study

(Division of Forest Products.—Technical Paper No. 2)

By

H. E. DADSWELL, M.Sc.

MELBOURNE, 1931

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PAMPHLET No. 21.

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CONTENTS.

FOREWORD.

Such data as are available in regard to the density of Australian timbers appear to be very unsatisfactory, as the figures for one species vary over a wide range. So pronounced is the variation that density as a diagnostic feature is useless.

One of the causes of this wide variation appeared to be the standards used in determining density. For this reason, the method outlined in Technical Paper No. 2 was developed.

The only new feature in this method is that by cutting three adjacent thin sections, using the centre one for volume determination and the two outer ones for moisture determination, the very uncertain factor of variation in shrinkage has been eliminated. Any method of drying to obtain an oven dry sample whose volume is to be found, inevitably introduces discrepancies due to the varying shrinkage with different conditions of drying.

Using this new method, the range within a species is considerably narrowed, and it appears as if density may prove very useful as one of the early factors in classification of timbers.

The paper describes the method and some of the results obtained by its use. A very large number of timbers are being examined for density, sections being cut for this purpose from all material sent in for identification studies. Later papers will be published, giving for the first time reliable density determinations on a uniform system for Australian timbers.

I. H. BOAS,

Chief, Division of Forest Products.

June, 1931.

SUMMARY.

(1) A method for the determination of density of woods has been investigated.

(2) This method involves the determination of the oven dry weight and the volume of the sample after soaking, and the results thus obtained are used in the calculation of density figures.

(3) From the experiments carried out, it has been concluded that soaking under water from five to six days is sufficient to restore the small samples used to their green dimensions and this has been found to be the case even with dried and collapsed samples.

(4) The possibilities of the method for general and identification purposes have been briefly studied in relation to the determination of the density of a number of samples from different species.

The Density of Australian Timbers.

A Preliminary Study.†

1. Introduction.

The determination of the density of wood is influenced by the fact that wood is not homogeneous but is made up of a large number of cells which have small or large cavities depending on their size and nature. Actually, the amount of solid woody material present comprises only a portion of the volume, and while the specific gravity of this wood substance is approximately 1.52, that of any piece of timber as a whole will vary considerably, depending on the number, size, form, and arrangement of the wood elements. The presence of water in the cell cavities and walls will alter the weight, and the volume will change as the wood is dried from the green condition. This alteration of volume, or shrinkage, will differ according to the method of drying employed. Thus, in any method for determining the specific gravity and subsequently the density of wood, it is necessary to take into account the presence of moisture and the shrinkage caused by the removal of such moisture.

Determinations have previously been based on the following different methods:—

(*a*) Weight of sample oven dry in relation to volume oven dry. (1) (2) (4) (5) (7) (7*a*) (8) (9)*.

(*b*) Weight of sample oven dry in relation to volume air dry. (3) (5).

(*c*) Weight of sample oven dry in relation to volume at time of test. (6) (7).

(*d*) Weight of sample oven dry in relation to volume green. (2) (3) (5).

(*e*) Weight of sample air dry in relation to volume air dry. (5) (9).

(*f*) Weight of sample at time of test in relation to volume at time of test. (7) (10) (11).

(*g*) Weight of sample green in relation to volume green. (1) (2) (5) (9).

The volume oven dry is determined on the oven dry sample by means of the displacement of water, absorption of moisture by the sample being prevented by giving it a thin coating of paraffin. "Air dry" is very indefinite; and the moisture content of an air dry sample will vary according to the atmospheric conditions and the length of time exposed. In most cases it is taken to represent 12% moisture content, but this will vary in Australia at least from 6% to 18%, depending on the period of the year and the locality. The weight or volume at the time of test will also vary considerably and will depend on the previous history of the sample. In such cases, it is customary to record the moisture content at the time of test. "Green" volume refers to the condition of the sample as taken from the living tree. Any method must give an arbitrary value for specific gravity, and figures are therefore valueless unless the basis of the determination is recorded. The best basis for calculating and for obtaining comparable results to be used in common

† Typescript received for publication 19th June, 1931. * See References to Literature, page 16.

practice has been a matter of dispute. The most commonly adopted methods are (*a*), (*e*), and (*g*) of the above. The method (*g*) is only of value when the sample is taken directly from green timber. Clarke(12), in 1930, suggested that the most reliable figures for specific gravity would probably be yielded by the ratio of oven dry weight to the saturated volume, but as yet this method does not appear to have been fully investigated.

2. Object of Investigation.

Numerous figures on the density of Australian timbers are available. In most cases, however, they are not accompanied by the record of the method used. In 1906, in his study of the timbers of Western Australia, Julius(9) used methods (*a*), (*e*), and (*g*). Swain(10), in the *Timbers and Forest Products of Queensland*, records average density figures for the various woods tested on the air dry basis, but does not mention the method employed in calculating these. Baker(11) listed figures for numerous woods on the basis of air dry, well seasoned timber, "having only, of course, its atmospheric absorbed moisture, which is generally 10 to 18 per cent."

A systematic survey of the density of Australian woods is important, but to be of any value this must be carried out by means of a standard procedure. If such a procedure be followed, density may then prove to be a factor of importance in the development of methods of wood identification. It is necessary, therefore, that the method adopted should be such that any investigator can by means of it obtain comparable results.

Certain other conditions also apply. Firstly, samples of varying moisture content will be received, and the method for determination of density must be effective, irrespective of the moisture content at the time of commencing the determination. Secondly, the bad collapse on drying of the eucalypts such as *E. regnans* (mountain ash) mitigates against the use of the oven dry or the air dry volume, because it is extremely unlikely that two pieces of wood from even the same stick will ever collapse in exactly the same way. Reduction in volume is also important, and in certain species, particularly some of the eucalypts, it occurs at a relatively high moisture content.

For obvious reasons, none of the above methods (*a*) to (*g*) comply with these conditions. Useful results have been obtained when the oven dry weight and volume green have been taken as the basis for calculation, but these conditions are not suitable when the sample to be tested is in an air dry state and some shrinkage or collapse has occurred. However, it was considered probable that prolonged soaking in water would tend to restore the sample to approximately its volume green, and in this way overcome changes in volume due to shrinkage and collapse. With the idea of studying the possibilities of developing a standard based on the oven dry weight and volume when soaked, the following points were investigated:—

(i) Time of soaking in water necessary to bring kiln dry and air dry samples to constant volume, the size and form of specimen being kept within certain limits.

(ii) Comparison of results obtained with the suggested method, using green, air dry, kiln dry, and oven dry samples from the same stick.

(iii) Comparison of results obtained by the suggested method with those obtained on the basis of the oven-dry weight and the oven dry volume, using the same samples.

(iv) Effect of prolonged soaking on the ultimate oven dry weight (i.e., loss due to solution of extractives).

(v) Variation within a tree and within a species.

(vi) The possibilities of the method as a standard, both for general purposes and for purposes of identification.

With reference to (iv) above, it was recognized that in the case of certain species the loss of weight on soaking might appreciably affect the oven dry weight. Hence it was decided to obtain the oven dry weight of the sample used for soaking by calculation from the average of those of the adjacent samples, and to compare this calculated oven dry weight with that obtained by oven drying the sample after soaking.

3. Experimental Procedure.

The details of the method employed are as follows:—Three adjacent cross sections $\frac{1}{4}$ inch to $\frac{1}{2}$ inch thick were cut at least 2 inches from one end of the sample. These were kept together and trimmed to approximately $2\frac{1}{2}$ inches x 1 inch, care being taken to secure only sound heartwood. (See Diagram I.) The two outside portions were marked with the laboratory number of the sample and a large M, while the centre-piece was marked with the laboratory number and a large D. After marking, all three were immediately transferred to an air-tight container preparatory to weighing. The two samples marked M were scraped free from splinters and sawdust, weighed together, and

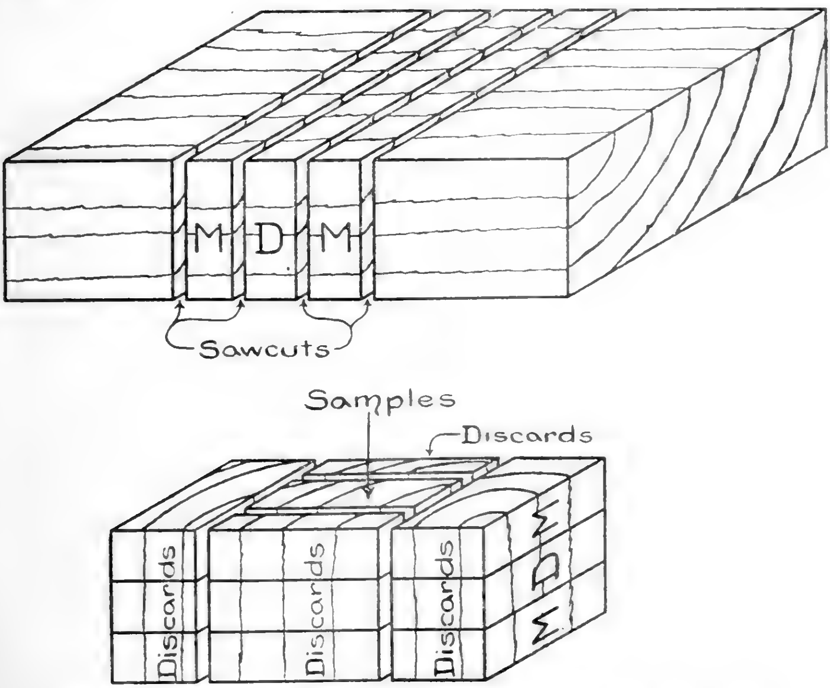


DIAGRAM I.—Showing the method of cutting moisture content and density samples for use in the determination of density.

transferred to an oven maintained at 105° C. When no further loss of weight was noticed, the oven dry weight was recorded. The sample D was scraped, weighed, and immediately immersed in water for a period sufficient to secure a constant volume. The volume was determined in the usual way by displacement of water*, care first being taken, however, to remove any excess water from the soaked sample by means of a cloth. The oven dry weight of sample D was calculated according to the following formula:—

$$\text{O.D. weight of D} = \text{original weight of D} \times \frac{\text{O.D. weight of M}}{\text{Original weight of M}}$$

The specific gravity of the sample was then calculated by dividing the oven dry weight (calculated) by the volume of the soaked sample. By multiplying this figure by 62.5, the density in lbs. per cubic feet was obtained. The oven dry weight of sample D, when re-dried after the determination of volume soaked, was also recorded.

4. Experimental Results.

1. Experiments were carried out which showed that the method employed for obtaining the oven dry weight of the density sample—i.e., by calculation from the known moisture content of the samples taken from either side of it—was reliable.

2. The time necessary for the density sample to reach a constant volume by the continued soaking of that sample was investigated. This time is naturally dependent, to some extent, on the original moisture content. It was found that samples with as low as 11 per cent. moisture required five to six days immersion under water to ensure their reaching a constant volume. Results obtained with two of the species investigated, using samples approximately $2\frac{1}{2}$ inches x 1 inch from cross sections $\frac{1}{4}$ inch to $\frac{1}{2}$ inch thick, are shown in Table I.

Table I.—*Showing Time necessary to reach Constant Volume (Soaked).*

Name of Wood.	Volume in c.c. at end of—			
	1st day.	2nd day.	4th day.	6th day.
E. microcorys	14·3	14·7	14·8	14·8
E. pilularis	17·1	17·7	18·1	18·1

3. Using four samples from different specimens of *E. regnans,* a species in which collapse during drying is very common, the following tests were made:—

(*a*) In the first place, the volume of the samples green from the saw was determined, after which they were soaked three days in water and the volume again determined. The samples, although in a very wet state when cut—moisture content approximately 100 per cent. on the oven dry weight—had apparently collapsed slightly, and the soaking for three days in all cases caused a very slight increase in volume and subsequent slight decrease in the values for density. (See Table II.) Apparently, slight collapse can occur even at very high moisture contents. It will, therefore, always be advisable to immerse samples for a few days before determining density, even if they are in a green condition and apparently at their greatest volume.

* The displacement being determined indirectly by measuring the buoyant force exerted by the sample on total immersion in water.

TABLE II.—*Density of Samples of E. regnans.*

No.	Calculated O.D. weight. (gms.)	Volume green. (c.c.)	Density on volume green. (lbs. per cu. ft.)	Volume soaked 3 days under water. (c.c.)	Density on volume soaked. (lbs. per cu. ft.)
1A1D ..	18·9	40·1	29·5	40·7	29·0
1B1D ..	26·2	46·4	35·2	46·9	34·9
1C1D ..	17·4	37·0	29·4	37·5	29·0
1D2D ..	16·3	36·4	28·0	37·2	27·4

(*b*) Further experiments were carried out with the same samples of *E. regnans.* In the first experiment, they were allowed to dry at room temperature in the sun for three days, by which treatment the moisture content was reduced considerably and the samples had collapsed to some extent. They were then immersed for two days and the volume subsequently obtained. The results showed that there was practically no difference from the original soaked volume. (See Table III.) In a second experiment, these same samples were dried in the sun and on top of an oven, until the moisture content had been reduced to approximately 12 per cent. There was evidence of considerable collapse. They were then soaked for four days and the volume of each determined. This was again practically identical with the original soaked volume. (See Table III.)

TABLE III.—*E. regnans—Results of Experiment (b).*

No. of Sample.	Moisture content after 3 days' air drying at room temperature. (per cent.)	Calculated O.D. weight. (gms.)	Volume after 2 days' soaking. (c.c.)	Density. (lbs. per cu. ft.)	Moisture content after 2 days in sun and on top of oven. (per cent.)	Volume after 4 days' soaking. (c.c.)	Density. (lbs. per cu. ft.)
1A1D	27·0	18·9	40·5	29·2	11·1	41·0	28·8
1B1D	29·8	26·2	47·0	34·8	13·1	46·7	35·1
1C1D	38·3	17·4	37·0	29·4	10·2	37·8	28·8
1D2D	65·6	16·3	36·8	27·7	11·4	37·0	27·6

(*c*) The same samples of *E. regnans* were finally oven dried at 105° C., and thus subjected to the most severe drying conditions. Soaking for six days was sufficient to restore them to their original soaked volume within the limits of experimental error. (See Table IV.)

TABLE IV.—*E. regnans—Results of Experiment (c).*

No.	Calculated O.D. Weight. (gms.)	Volume soaked (6 days immersed). (c.c.)	Density. (lbs. per cu. ft.)
1A1D ..	18·9	40·5	29·2
1B1D	26·2	47·0	34·8
1C1D	17·4	37·0	29·4
1D2D	16·3	36·3	28·1

4. The suggested method was shown to give more uniform results throughout a species than that based on the oven dry weight and the oven dry volume. Up to the present the latter basis for calculation has been the one most commonly adopted for the determination of specific

gravity and density. A number of samples of jarrah (*E. marginata*) and karri (*E. diversicolor*) were used, and the new method outlined above was followed in the determination of density. At the same time, portions of the same samples were used for the determination of density by one of the older methods, namely, that based on the ratio of oven dry weight and oven dry volume.* Thus direct comparison of results by the two methods using the same samples was possible (see Table V.). It will be noted on examination of these results that method (i)—i.e., the proposed standard—gives the more uniform results, the range in the case of the jarrah samples examined being 38.9 to 45.8 lb. per cubic foot, a difference of 6.9 (18% on the lower figure), while the corresponding range with method (ii) is 43.8 to 58.5 lb. per cubic foot, a difference of 14.7 (33% on the lower figure). This larger variation with method (ii) is due to the uneven shrinkage of the samples both prior to and during oven drying, causing marked divergencies in the oven dry volume.

TABLE V.—*Results of Density Determinations—Karri and Jarrah.*

Name.	No. of Sample.	Moisture Content.	Density in lbs. per cu. ft.	
			(1) Based on O.D. weight and volume when soaked.	(2) Based on O.D. weight and volume oven dry.
		%		
E. diversicolor (Karri) ..	A1	30·0	45·6	56·4
,, ,, ..	B6	36·0	41·0	53·6
,, ,, ..	C10	32·0	46·1	55·2
,, ,, ..	D13	37·3	46·1	56·8
,, ,, ..	3	29·7	37·9	46·8
E. marginata (Jarrah) ..	A2 butt	25·9	40·3	47·6
,, ,, ..	A6 crown	26·6	44·4	53·1
,, ,, ..	B7	33·1	39·9	50·4
,, ,, ..	C11	39·6	38·9	49·2
,, ,, ..	D14	29·7	45·3	58·5
,, ,, ..	903	28·4	45·8	55·0
,, ,, ..	904	28·3	39·3	46·2
,, ,, ..	905	29·8	46·1	45·6
,, ,, ..	906	31·9	43·7	53·8
,, ,, ..	907	31·2	40·5	47·5
,, ,, ..	908	25·7	40·7	48·7
,, ,, ..	909	31·9	42·4	50·0
,, ,, ..	910	30·6	39·7	46·2
,, ,, ..	911	28·1	41·7	50·0
,, ,, ..	912	32·2	41·5	48·1
,, ,, ..	913	30·2	41·9	48·8
,, ,, ..	914	25·6	40·9	47·5
,, ,, ..	915	26·9	41·5	48·8
,, ,, ..	916	30·2	40·8	47·5
,, ,, ..	917	30·4	39·0	43·8
,, ,, ..	918	31·8	44·0	50·7
,, ,, ..	919	29·9	41·8	48·8
,, ,, ..	920	29·9	42·4	46·9

5. By using the method described above, the question of the loss of weight due to prolonged soaking of the density sample in water is not a problem, as the oven dry weight of the sample is obtained otherwise. However, it was considered necessary to show that the loss of weight

* To obtain the oven dry volumes, the hot oven dry samples were, after weighing, dipped into melted paraffin and allowed to drain. Excess paraffin was removed by scraping with a knife, and the volume determined by displacement of water in the usual way. (See footnote page 10).

on soaking was sufficient to cause an appreciable difference in density if the oven dry weight was determined on the sample after soaking. For this purpose, the actual oven dry weights of a number of samples of different species of the genus *Eucalyptus* were determined after the samples had been used for determination of soaked volume. The resulting figures were compared with those obtained for the same samples by calculation according to the method outlined. Typical results for each species investigated are shown in Table VI.

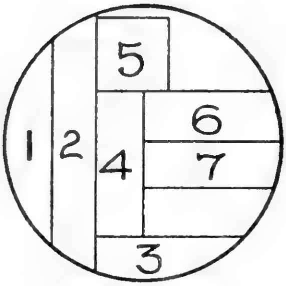
TABLE VI.—*Effect of Loss of Weight, due to Prolonged Soaking, on Density Results.*

Name.	No. of Sample.	Calculated O.D. weight (1).	Actual O.D. weight after soaking (2).	Difference.	Density (in lbs. per cu. ft.).	
					Using (1).	Using (2).
E. crebra	1194	18·83	18·80	0·03	58·7	58·7
E. sideroxylon ..	1319	14·45	14·15	0·30	53·9	52·7
E. siderophloia ..	990	16·70	16·60	0·10	57·9	57·5
E. longifolia ..	508	14·99	14·50	0·49	50·7	48·9
E. tereticornis ..	1306	21·62	21·13	0·49	49·4	48·2
E. polyanthemos ..	1512	16·55	15·80	0·75	55·2	52·7
E. paniculata ..	720	11·02	10·75	0·27	54·9	53·5
E. rostrata	617	10·47	10·00	0·47	45·6	43·6
E. resinifera ..	1295	17·22	17·05	0·17	48·7	48·2
E. gomphocephala ..	1375	13·80	13·49	0·31	46·9	45·8
E. patens	1378	15·01	14·79	0·22	44·5	43·7
E. redunca var. *elata*	1391	16·15	15·75	0·40	56·0	54·7
E. salubris ..	1418	11·53	11·47	0·06	51·6	51·2
E. salmonophloia ..	1415	12·61	12·58	0·03	56·3	56·0
E. pilularis ..	1447	16·65	16·25	0·40	37·1	36·1
E. piperita ..	1443	14·00	14·00	..	35·2	35·2
E. corymbosa ..	1452	12·72	12·69	0·03	44·0	43·9
E. hemiphloia ..	1548	13·81	13·50	0·31	55·5	54·2

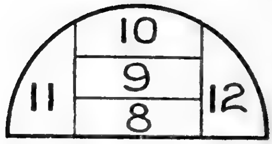
6. It has been shown that the method under investigation gives more uniform results because variations due to shrinkage and collapse have been overcome. For this reason, it was considered that it would be of interest to apply the method to the determination of the density of samples from different parts of the one tree and from different trees of a species. For the former investigation, samples were collected from a red ironbark (*E. sideroxylon*) and were taken from the trunk at levels of 5 feet, 15 feet, 25 feet, and 35 feet from the ground. The distribution of the eighteen samples thus collected is shown in Diagram II. The results obtained for heartwood samples are shown in Table VII. It was not intended to make a systematic study of the variations of density within a tree, but only to observe the uniformity of results obtained, using the proposed method. It will be seen that the variation is not great, the density decreasing slightly with the height of the sample from the ground.

TABLE VII.—*Variation of Density in Samples from Different Positions in the Same Tree.*

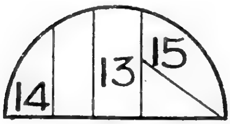
Position No.	Density (lbs. per cu. ft.).	Position No.	Density (lbs. per cu. ft.).
2	56·1	11	55·4
3	56·7	12	54·6
4	55·0	13	54·6
5	54·4	14	53·9
6	56·5	15	54·5
9	55·8	16	54·7
10	56·3	17	53·0



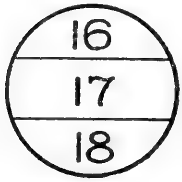
Cross Section No. 1.
5 feet from ground.



Cross Section No. 2.
15 feet from ground.



Cross Section No. 3.
25 feet from ground.



Cross Section No. 4.
35 feet from ground.

DIAGRAM II.—Showing the distribution of the samples of red ironbark used in studying the variation of density within the tree.

Results obtained by this method for a number of samples from different species are shown in Table VIII. The different samples for each species were obtained from different localities, and were taken from the heartwood at various positions in the tree. Again no attempt was made to study systematically the variation of density within a species, but it is of interest from the aspect of wood identification to observe the general uniformity of results obtained for each species using the method under investigation.

TABLE VIII.—*Density Values for a Number of Eucalypts.*

Name.	Number of samples examined.	Density (in lbs. per cu. ft.).		
		Maximum.	Minimum.	Average.
E. crebra	15	59·2	52·2	56·1
E. sideroxylon	15	57·2	52·8	54·9
E. siderophloia	11	59·2	55·8	57·4
E. paniculata	10	59·2	51·2	55·7
E. polyanthemos	10	58·6	52·6	54·9
E. rostrata.. ..	14	47·2	37·8	43·6
E. resinifera	12	50·4	40·8	45·9
E. gomphocephala	11	56·0	46·9	51·4
E. patens	12	48·5	37·5	42·7
E. redunca var. *elata* ..	12	60·6	53·6	57·9
E. accedens	13	59·1	52·5	57·4
E. salubris	11	60·0	51·6	55·1
E. salmonophloia	10	58·4	53·8	56·0
E. tereticornis	9	51·2	45·7	48·5
E. marginata	23	45·8	38·9	41·6
E. sieberiana	9	56·1	37·6	45·8
E. obliqua	9	42·8	28·4	35·4
E. gigantea	7	35·8	31·0	34·1
E. regnans	9	35·0	23·9	27·9
E. pilularis	21	52·7	36·6	44·3
E. microcorys	9	55·8	47·7	51·8

5. Discussion of Results.

As a result of these preliminary experiments, it seems that the proposed method for determining the specific gravity and density of wood is quite satisfactory. The figures actually obtained are lower than those given by the use of other methods. The basis adopted for calculation, oven dry weight and volume when soaked, implies the lowest possible weight and the greatest volume.

Soaking under water has been shown to bring a sample to constant volume within five to six days, and the experiments with *E. regnans,* a timber in which collapse is very prevalent, demonstrated that such soaking definitely returned collapsed samples to their green dimensions. Thus the treatment by means of which the sample is brought to its greatest volume apparently removes many of the difficulties caused by shrinkage and collapse which materially affect values for oven dry or air dry volume. Owing to the effects of collapse, the density figures for two samples from the one stick based on oven dry weight and oven dry volume, may differ widely. On the other hand, it has been shown that, with the proposed method, the soaked volume will not vary, and results based on it will always be comparable.

The determination of the oven dry weight of a sample after it has been soaked in water is not recommended, because it has been shown that there is in many cases a definite loss of weight due to the solution of extractives. The method suggested for determination of the oven dry weight of the density sample by calculation has proved quite satisfactory and reliable. In cases where the sample to be used for density determination is too small for treatment as suggested, it would be advisable to determine the oven dry weight of the sample before soaking to constant volume. This procedure is, however, not recommended for general use because of the danger of the splitting of the sample during the oven drying, and because it has yet to be shown that oven dry samples of all woods will return to green dimensions on soaking.

The knowledge of the density of different species is of great value, since it has been shown by the U.S. Forest Products Laboratory(3) that there is a relationship between density and mechanical properties. Thus it is important that the method employed for the determination be such that results are generally comparable, and that any errors due to abnormal shrinkage, collapse, &c., are obviated. It is suggested that the method outlined in this paper is one which will give the most uniform results, and for this reason should be employed in the study of the density of the numerous Australian woods. Density may have an important bearing on the development of keys for the identification of these woods, and accordingly it is necessary that all the results obtained be based on the same method. The preliminary work described in this paper shows that the method suggested should prove to be most suitable in this connexion. It may be argued that it is often necessary to obtain the density of a sample within a short time, in which case soaking for five to six days would be out of the question. However, if the shrinkage of the sample is known, it would be possible to obtain an approximate value for the soaked volume, and thus record the information according to standard. On the other hand, this procedure will have to be used with caution, as collapse may have occurred.

It is recognized that further investigations with the method are desirable, and these will be carried out and reported later.

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MELBOURNE.

PAMPHLET No. 22.

COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

The Chemistry of Australian Timbers

Part I.—A Study of the Lignin Determination

(Division of Forest Products.—Technical Paper No. 3)

By

W. E. COHEN, B.Sc., and H. E. DADSWELL, M.Sc.

MELBOURNE, 1931

Registered at the General Post Office, Melbourne, for transmission through the post as a book.
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CONTENTS.

FOREWORD.

Technical Paper No. 3 covers investigations on two aspects of wood analysis, which have arisen during the progress of work on a project (C1-1) of this Division. This project concerns a study of the chemical composition of Australian hardwoods. From this main investigation several minor ones have arisen with definite economic aspects.

During the course of the work two problems developed, viz., the proper sampling of the wood for analysis and the accurate estimation of lignin.

Methods for both of these have been standardized in the United States, but certain characteristics of Australian hardwoods brought out what appear to be serious errors in the standard practices. The errors only become marked when the wood contains large quantities of more or less brittle resinous matter. While several workers have been aware of the difficulty, as is indicated in the review of the literature, no one appears to have recognized the possibility of large errors in sampling or to have demonstrated a method of determining lignin suitable for all woods and free from the errors caused by resinous material not removed by standard procedure.

This paper deals with an attempt to demonstrate these errors and to suggest how they can be overcome. It is the first paper of a series on the chemical composition of Australian hardwoods.

I. H. BOAS,
Chief, Division of Forest Products.

June, 1931.

SUMMARY.

1. Representative samples of the Eucalypts in particular, and of all woods in general, cannot be obtained unless all of the wood is reduced to powder and included in the sample.

2. Microchemical studies have shown that the Eucalypts, and the softwoods, hemlock and spruce, contain substances which are of an extraneous nature and which are not soluble in benzene-alcohol.

3. By means of the microscope, these substances have been shown to remain with lignin when it is isolated by the standard procedure.

4. Microscopic examinations of wood powder have shown that a number of organic solvents and some neutral salts do not dissolve the extraneous material from Eucalypts, but that weak solutions of sodium hydroxide readily remove it.

5. A sodium hydroxide solution, when applied to thin sections, removes all visible extraneous material in 80 minutes, without, as far as can be seen by the microscope, attack on the wood structure.

6. Quantitative chemical analyses have been used to demonstrate that the sodium hydroxide in weak solutions does not attack the lignin of hemlock and spruce, the apparent loss in lignin being due to the removal of extraneous material from the ray cells.

7. The chemical studies which have been extended to jarrah, red ironbark, and mountain ash, have shown that reasonable values for lignin can be obtained when wood powder is previously purified by treatment with weak sodium hydroxide solution.

8. A procedure for this preliminary purification is outlined.

The Chemistry of Australian Timbers.

Part I.—The Study of the Lignin Determination.

1. Introduction.

The results of a preliminary investigation of the chemical composition of certain members of the genus *Eucalyptus* indicated that an abnormally high lignin content was obtained when the standard method of estimation, as adopted by the U.S. Forest Products Laboratory, was followed. This method(1) is:—Two grams of air-dried sawdust (80-100 mesh) are extracted for four hours with a minimum boiling point mixture of benzene and alcohol (2:1). The extracted wood is dried and treated with 72 per cent. sulphuric acid in the cold for sixteen hours, the acid diluted to 3 per cent., and the solution boiled for two hours under reflux. The residue is then filtered on a tared alundum crucible, washed free from acid with hot water, dried at 105 deg. C., and weighed as lignin.

In the majority of cases the recorded apparent lignin content for numerous North American hardwoods is in the vicinity of 25 per cent., based on the oven dry weight of the wood analysed(2). On the other hand, the apparent lignin content of jarrah (*E. marginata*) varied from 38.9 per cent. to 54.5 per cent., depending on the sample examined. This high lignin content and wide variation within a species was also found for members of the ironbark group, namely, red ironbark (*E. sideroxylon*), 28.0 per cent. to 40.5 per cent.; broad-leaved ironbark (*E. siderophloia*), 33.2 per cent. to 50.1 per cent.; narrow-leaved ironbark (*E. crebra*), 36.9 per cent. to 48.3 per cent.; grey ironbark (*E. paniculata*), 28.2 per cent. to 36.1 per cent.; and grey gum (*E. propinqua*), 34.2 per cent. to 38.8 per cent. Certain other species on examination similarly showed high lignin contents. These figures indicated that the existing standard procedure, outlined above, resulted in the isolation of lignin contaminated by other materials. A microscopic examination of lignin isolated from the above woods revealed the presence of large numbers of particles obviously dissimilar from the powdered lignin and apparently of a gum-like or resinous nature (see Figure 1, page 8).

When thin sections of each of the above species were examined microscopically, large quantities of dark-coloured substances were observed in the vessels, ray cells, wood parenchyma, and even the lumina of the wood fibres. After careful examination, it was concluded that this material was the same as that isolated with the lignin.

The extraction of benzene-alcohol is carried out to remove resins, gums, and other materials which would resist the treatment with 72 per cent. sulphuric acid, and consequently would be isolated with the lignin. Although it has not been claimed that this solvent removes all substances from the wood that would otherwise be isolated with lignin, it has been used with apparent success in a large number of lignin determinations on North American species(2). That this is not the case for woods of the genus *Eucalyptus* was exemplified by the analysis of one sample of jarrah which, after prolonged extraction with benzene-alcohol (2:1), lost 1 per cent. and still showed an apparent lignin content of 54.5 per cent. While in this instance the solubility in benzene-alcohol was extremely low, it was found, in the case of the

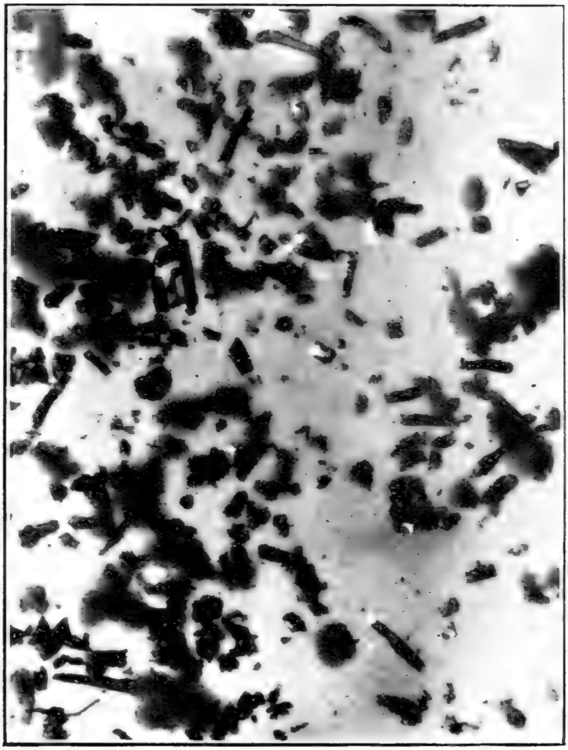

Fig. 1

Fig. 1.—A photomicrograph of lignin isolated from jarrah by the standard procedure and consequently contaminated with gum-like material. The latter is clearly seen as well defined black opaque objects, which in a number of instances are reflecting the light. × 85.

ironbark group of eucalypts, that this factor varied according to the species. For example, samples of red ironbark had a greater amount of material soluble in benzene-alcohol (8.0 per cent. to 29.5 per cent.) than other members of the group (less than 10 per cent.). This variation depends on the nature, and hence the solubility, of the material in the vessels, rays, wood parenchyma, and lumina of the fibres.

(Note.—In addition, these substances are very brittle and are readily reduced to a fine dust in a mill, thus giving rise to a variation in the quantity retained on a 100-mesh sieve, even for two samples prepared from one piece of wood. When a sample of wood is ground in a mill and sieved to separate that portion which passes through an 80-mesh sieve, it is apparent that any brittle material in the wood will tend to concentrate in the reject passing through the smaller meshed sieve. For this reason, the existing standard procedure for sampling is unsatisfactory. Serious sampling errors arise in those woods that contain much of these resinous materials, and even in the softwoods the error may be appreciable. In support of this argument, the following results of analyses are included. In this case, an 80-100 mesh sample (A) of red ironbark was obtained, together with a sample (C) of the rejected material (passing through the 100-mesh sieve). After removing a smaller sample of (A) sufficient for analytical purposes, the remainder was ground to pass through the 100-mesh sieve, thus providing sample (B). The three samples (A, B, and C) were then examined by the standard procedures and the following results, based on the oven dry weight of wood, were obtained:—

	(A)	(B)	(C)
	Per cent.	Per cent.	Per cent.
Soluble in alcohol	17.0	17.2	26.6
Soluble in benzene-alcohol (2:1) ..	5.4	5.3	8.1
Soluble in ether	1.8	1.7	2.6
Soluble in N/4 sodium hydroxide ..	31.7	32.3	43.1
Lignin	39.7	39.1	41.7
Cellulose	40.7	39.6	34.5
Pentosans in wood	16.2	16.9	14.9

It was also noticed, by microscopic examination, that in the 80-100 mesh material, there were some comparatively large pieces of free resinous substances, and some still enclosed in wood cells that had not been completely disintegrated. Any procedure, therefore, which rejects the finest product of the grinding must be unsatisfactory. The sample will not be representative of the original wood.

In order to yield a true sample, the whole of the wood used must be ground to pass the desired mesh. The failure to observe this precaution in the past throws doubt upon the accuracy of many published analyses of woods.)

Since benzene-alcohol failed to dissolve the material completely, even in a fine state of division, the lignin determination was correspondingly affected. The problem then amounted to the development of some other method of purification. Two alternatives immediately presented themselves, (i) the use of other neutral solvents, (ii) the application of weak alkaline solutions. The latter are known to dissolve free kino, which, in the case of a large number of species of the genus *Eucalyptus* occurs as an exudation from, and as gum pockets or veins within, the tree. It was considered that the materials in the vessels, rays, &c., of the wood were closely related to, if not identical with, this kino. In this present publication they have been grouped and referred to as "extraneous material." Thus, preliminary purification with dilute alkali to remove this material seemed to be a possibility, but the danger of the removal of some of the lignin complex by such treatment would need to be considered.

2. Historical.

Schorger(3) has stated that, under present conditions, all substances insoluble in the acids used in the lignin determination are estimated as lignin. He considered that, in addition to extraction with benzene-alcohol, a preliminary purification that would not remove lignin was needed, and he suggested dilute ammonia for this purpose.

Some of the early workers on wood chemistry, viz., Stackmann(4) and Schuppe (5), used both neutral and alkaline solutions to dissolve the gums, resins, fats, &c., from the wood preparatory to the isolation of lignin.

The extraction with alkaline solutions did not, however, find favour because, according to Pringsheim and Magnus(6), the presence of acetates after treatment of wood with cold alkali solutions was taken, with a good deal of assurance, as an index of the presence of acetyl groups in lignin.

Dore(7) also reported that the cold alkali treatment completely removed the acetyl groups from the wood, as he found very little remaining in lignin subsequently isolated by means of 72 per cent.

sulphuric acid. (It is recognized that alkaline solutions will remove acetyl groups, but it is to be remembered that any treatment with dilute acid, such as 3 per cent. sulphuric acid, will also remove them.) In addition, Hawley and Wise(8) have stated that no lignin fraction has as yet been isolated from wood that was capable of yielding more than minimal amounts of acetic acid when treated with acids or alkalis. In spite of this loss of acetyl groups, Dore(9) recommended the preliminary purification of hardwoods by consecutive extractions with benzene-alcohol, water, and cold 5 per cent. sodium hydroxide solution. He found that the methoxyl content of live oak was not affected by this purification, although the acetyl groups were almost completely eliminated. The lignin content of the wood purified in this manner was found to be 20.3 per cent., while that extracted only with alcohol and benzene varied between 22.1 per cent. and 25.5 per cent. He claimed that these treatments removed all adventitious substances, but did not injure either the cellulose or the lignin.

For coniferous woods, Dore(10) specified a preliminary purification using benzene and alcohol consecutively. On the other hand, von Euler(11) claimed that the preliminary extraction of the wood with alcohol removed some constituents related to, and properly belonging to, the lignin.

Bechmann, Liesche, and Lehmann (12), in a study on the extraction of lignin from both hardwoods and softwoods (previously purified with ether) by means of sodium hydroxide, found that, after 48 hours in the cold followed by six hours boiling under reflux with 1.5 per cent. sodium hydroxide, the yield of so-called lignin only amounted to about 3 per cent. of the oven dry wood.

Klason(13) has attempted to obtain uncontaminated lignin by washing the product obtained by acid treatment with hot alcohol to remove resins and fats, and with N/10 potassium hydroxide to neutralize residual sulphuric acid.

Preparatory to the isolation of lignin from pine wood for constitution studies, Friedrich and Diwald(14) freed the wood meal from resins by extraction with benzene-alcohol and from gums by extracting it four times (each of 36 hours) with 5 per cent. sodium hydroxide at room temperature. In a subsequent paper, Friedrich and Brüda(15) have emphasized the necessity for this method of purification, in order to avoid complications in the study of the constitution of lignin from white beech. Horn(16) has studied the purification of wood from hemicelluloses and gums, using cold 5 per cent. sodium hydroxide solution in addition to benzene-alcohol (1:1). He expressed the opinion that, in the presence of sodium hydroxide, lignin may be oxidized or its components split off, possibly by saponification, and that the residue may be altered. He recommended the use of 5 per cent. sodium hydroxide in the cold for de-gumming wood, even though he considered that a part of the lignin had been removed.

According to Schorger(17) it remains to be shown that such alkaline treatments do not remove a portion of the lignin. On the other hand, Ritter(18) in his work on the distribution of lignin, has stated that, after treatment of wood sections at 52 deg. to 54 deg. C. with 3 per cent. hydrochloric acid and with 3 per cent. sodium hydroxide alternatively for a total period of one and a half hours with each reagent, the middle lamella remained intact with no apparent signs of solvent action by the acid-alkali treatment.

A number of investigators have of recent years published results of analyses of wood after extraction with sodium hydroxide. Hawley and Campbell (19) found that, on extracting 60-80 mesh sawdust from sitka spruce with 1 per cent. sodium hydroxide for one hour at 100 deg. C., the apparent lignin content on the basis of the original oven dry wood was reduced from 29.3 per cent. to 27.7 per cent. Ross and Hill(20) found that on extraction with 1 per cent. sodium hydroxide for six hours at 100 deg. C., the apparent lignin value was reduced in the case of spruce, balsam fir, poplar, chestnut, and cherry. They also ascertained that the loss on alkali extraction was practically constant after six hours, and raised the question as to whether the alkali removed further impurities or just slowly attacked the lignin, if considered to be a homogeneous body. They formed the opinion that lignin obtained from wood thus purified should be valuable raw material for a lignin investigation. Subsequently(21), they studied the progressive extraction of chestnut sawdust with boiling 1 per cent. sodium hydroxide, and estimated the lignin in the residues obtained. They found that the final residue was almost completely resistant to the solvent action of the dilute alkaline solution employed, and that there was apparently a definite ratio of lignin to cellulose in the wood that had been extracted for 24 hours. Campbell and Booth(22) examined the heartwood and sapwood of English oak, and found that the apparent lignin content was reduced in both when the 80-100 mesh sawdust was treated for one hour with 1% sodium hydroxide at 100 deg. C. (It is rather remarkable in this case that the lignin contents of the purified sapwood and heartwood were in closer agreement than before, and this is as one would expect.)

In no instance have attempts been made to define the alkali-soluble portions of wood. In some cases, the apparent loss in lignin has been explained by greater purification, i.e., removal of gums, &c., which would otherwise contaminate the isolated lignin, while definite solution of lignin has been assumed in other cases. There was not, however, any conclusive evidence to prove that weak alkaline solutions do attack and remove lignin from wood. In addition, no other solvent was suggested which could be applied to the eucalypts, without further investigation, in order to remove the extraneous material. Ross and Hill, as well as others, have shown that the difference between the apparent lignin content on wood purified with benzene-alcohol and on that purified with 1 per cent. sodium hydroxide solutions amounted to about 3 per cent. These losses could be represented by resins, gums, and extraneous matter generally which are insoluble in benzene-alcohol but soluble in the sodium hydroxide solution, rather than a degradation of the lignin. In any case, they are unimportant when it is considered that as much as 60 per cent. of the material isolated as lignin from some eucalypts after purification with benzene-alcohol, consists of extraneous matter.

3. Outline of Investigation.

The main object of the investigation amounted to a search for a reagent—organic, inorganic, neutral, or otherwise—that would dissolve the extraneous substances in the eucalypts, but not the lignin. Another important object was concerned with the preparation of true samples—which subject has already been dealt with in the introduction.

Since the consensus of opinion seemed to be that weak alkaline solutions do attack lignin, the possibilities of organic solvents and neutral solutions were first explored. For this purpose, fine wood powder was treated with a number of solvents and the purified material examined microscopically for the presence of extraneous substances, and chemically for the lignin content. The experiments were made with hemlock, red ironbark, and jarrah, and only served to prove that some organic solvents and some neutral salts neither removed all the extraneous substances nor attacked the lignin. It therefore appeared that further work with neutral reagents was not justified.

Jarrah having been found to contain a large amount of extraneous material, tests with weak alkaline solutions were naturally first applied to this wood. Studies were made qualitatively, quantitatively, and microscopically, and certain very promising results were soon obtained, in that weak solutions of sodium hydroxide were found to dissolve the extraneous substances. It became necessary at this stage to prove that the sodium hydroxide neither attacked the lignin nor affected the wood structure in thin sections. For this purpose, hemlock wood powder was treated with different strengths of weak sodium hydroxide solutions for increasing periods of time and the effect on the lignin content determined. At the same time, thin sections were similarly treated and examined microscopically for any interference in the wood structure that might have been caused. The experiments were extended to spruce, red ironbark and mountain ash (*E. regnans*).

4. Experimental Details.

(i) *Preparation of samples.*—Before proceeding with the study, it was essential to ensure uniform and representative samples. The difficulties arising from using samples of 80-100 mesh have already been discussed in the introduction. In view of these, the following conditions were adhered to in the preparation of samples for analysis:—

An entire block was cut from the wood sample and sawn into strips, all of which were ground in a laboratory impact mill until reduced to pass through a 100-mesh sieve. A final sample of 200 grams of this wood powder was obtained in order to reduce the error caused by the necessity for rejecting a small amount which the mill would not grind. The sample was thoroughly mixed, and reduced by quartering to a convenient size for laboratory purposes. The remainder was placed in reserve.

The material from which sections were cut for microscopic studies was obtained from the same bulk wood sample.

(ii) *Extraction with neutral solvents.*—The samples were treated in Soxhlet extractors with the following solvents:—Benzene-alcohol mixtures (2:1 and 1:1), ethyl alcohol, methyl alcohol, ether, carbon tetrachloride, acetone, hot and cold water. In addition, extractions with alcohol and the benzene-alcohol mixtures were followed by hot water in hot extractors. The extracted wood in all cases was examined microscopically for the presence of extraneous matter and the apparent lignin content determined.

In addition to the above-mentioned solvents, some qualitative tests were made with the neutral salts, sodium acetate, ammonium acetate, and ammonium oxalate. These extractions were carried out in open beakers at the temperature of the boiling water-bath for one hour. The extracted wood was filtered off, dried, and examined under the microscope for extraneous matter. The effect of these reagents was studied on the following woods:—Red ironbark, narrow-leaved ironbark, jarrah, red mahogany (*E. resinifera*), and Canadian hemlock.

Microscopic examination of the treated samples of the eucalypts revealed that the extraneous matter had not been completely dissolved, although in some cases 12 to 15 per cent. of the wood powder was removed. Since the results were negative in nature, it is not proposed to record them here.

It is interesting to note, however, that in the case of hemlock, although the amount extracted varied considerably with alcohol, benzene-alcohol, hot water, and combinations of these, the apparent lignin content remained constant. Thus, the lignin content, calculated on the oven dry weight of the original wood, when various solvents were used, was—

Lignin content.		Solvent used.
29.8	..	Benzene-alcohol (2:1).
29.8	..	Alcohol.
29.2	..	Hot water followed by alcohol.
29.3	..	Hot water followed by benzene-alcohol (2:1).

These results led to the conclusion that alcohol does not remove substances belonging to lignin, or conversely, if alcohol does remove such substances, then equally does a 2:1 benzene-alcohol mixture. The slight decrease obtained when hot water extraction was followed by either alcohol or benzene-alcohol suggests that hot water has removed either a portion of the lignin or a small amount of extraneous material that is insoluble in either alcohol or benzene-alcohol (2:1).

(iii) *Extraction with weak alkaline solutions.*—

(*a*) *Qualitative.*—The qualitative study of the effect of weak alkaline solutions was confined to the fine wood powder of jarrah. The reagents used and the various conditions applied were as follows:—

Reagent.	Strength of Reagent.	Temperature.	Time of Treatment.
Ammonia	1%	98°–100° C. ..	1 hour
,, ...	10%	98°–100° C. ..	1 hour
,, ...	10%	Room temperature	24 hours
,, ...	35%	Room temperature	24 hours
Sodium sulphite ..	2%	98°–100° C. ..	1 hour
Sodium bisulphite ..	2%	98°–100° C. ..	1 hour
Sodium carbonate ..	2%	98°–100° C. ..	1 hour
,, ,, ..	5%	98°–100° C. ..	1 hour
Sodium hydroxide ..	N/4	98°–100° C. ..	10, 20, 40, and 80 minutes
,, ,, ..	N/8	98°–100° C. ..	20, 40, and 80 minutes
,, ,, ..	N/20	98°–100° C. ..	20, 40, and 80 minutes
,, ,, ..	1.25N	Room temperature	72 hours (three successive periods of 24 hours)
Sodium biborate ..	5%	98°–100° C. ..	1 hour
Lime water ..	1%	98°–100° C. ..	1 hour
,, ,, ..	2%	98°–100° C. ..	1 hour

After treatment according to the above-mentioned details, the residual wood powder in each case was washed with hot water, 10 per cent. acetic acid, again hot water, dried, and then examined microscopically for the presence of extraneous matter. This appeared to be almost completely removed by N/20, N/8, and N/4 sodium hydroxide solutions in the course of 80 minutes heating at 98-100 deg. C. At room temperature, 1.25 N. sodium hydroxide attacked the extraneous material gradually, but after three successive treatments of 24 hours, a quantity of free material still remained. This treatment has been recommended and used in the past, particularly by Friedrich(14), but as applied to eucalypts, such as jarrah, the method is laborious, subject to many filtering difficulties, and not at all applicable to routine analyses. None of the other reagents completely removed the extraneous material, which in each case was visible when the extracted wood powder was examined under the microscope by transmitted, reflected, and polarized light.

These qualitative tests indicated that weak sodium hydroxide solutions effectively removed the extraneous material, but there was no evidence that the lignin was unattacked and the wood structure unaltered.

(*b*) *Quantitative.*—As a result of the above, quantitative studies were carried out in order—

(i) to ascertain the minimum strength of sodium hydroxide solution, and time of treatment necessary to obtain complete purification of the wood powder;

(ii) to determine the extent of attack, if any, on the lignin; and

(iii) to compare the lignin results obtained after benzene-alcohol extraction with those after extractions with the weak sodium hydroxide solutions, using Canadian hemlock and spruce as well as certain eucalypts, namely, jarrah, red ironbark, and mountain ash.

For this purpose, solutions of N/20, N/8, and N/4 sodium hydroxide were used at the temperature of boiling water to extract the wood powder for periods of 20, 40, 60, 80, 160, and 320 minutes. All extractions were made in duplicate, and concentration of solutions avoided by the use of reflux condensers.

Method.—The sample (approximately 3.0 grams) was weighed into an Erlenmeyer flask (300 cc.) which was fitted with an air condenser, and the sodium hydroxide solution (100 cc.) added. The flask and contents were then heated in the boiling water bath for a stipulated period. The contents were immediately filtered into a weighed alundum crucible, and the sodium hydroxide removed by suction and subsequent washing with hot water. Acetic acid (10 per cent.) was added and washing with hot water continued until the crucible and contents were acid-free. They were then dried at 105 deg. C., weighed, and the material soluble in the alkali determined.

(It was found necessary in the case of jarrah to increase the amount of N/20 sodium hydroxide used to 150 cc. in order to obtain a more complete solution of the extraneous material present.)

The dried extracted wood powder was removed from the alundum crucible and weighed for the determination of lignin by the 72 per cent. sulphuric acid method. The results were calculated on the basis of the oven dry weight of the original wood sample.

This procedure was followed with the three concentrations of sodium hydroxide, in the cases of Canadian spruce, Canadian hemlock, and jarrah. Red ironbark and mountain ash were treated only with N/8 sodium hydroxide. The results for alkali-solubility and lignin are shown in Table I., and for comparison have been plotted for each species (see Diagrams 1 to 5). Results (solubility and lignin) obtained when the woods were treated with benzene-alcohol are also included in the table and in the diagrams.

In order to follow the course of the alkaline treatment and its effects on the wood structure, thin tangential and cross sections of hemlock, spruce, and jarrah were extracted with the N/20, N/8, and N/4 sodium hydroxide solutions used for purifying the wood powder and under similar conditions. Length of treatment was limited to 40, 60, and 80 minute periods. The extracted sections were washed with water, treated with acetic acid (10 per cent.), washed again with water, and finally mounted for microscopic examination. At the same time, sections from these three species were extracted with benzene-alcohol (2:1) in order to observe the effect of this solvent on the extraneous material present. These sections were subsequently treated upon microscopic slides with 72 per cent. sulphuric acid, and the resulting lignin material examined. Photo-micrographs of the sections before and after treatment were taken and are reproduced in Figures 2 to 16.

5. Results and Discussion.

It is considered that representative samples of the eucalypts in particular, and of all woods in general, cannot be obtained unless all of the wood is reduced to powder and included in the sample. The procedure of taking only 80-100 mesh material is not satisfactory, because it has been found that the greater proportion of the extraneous matter passes through the 100-mesh sieve. Experience with the eucalypts has shown that it is very difficult to find a procedure whereby uniformly 80-100 mesh wood powder is obtained, and this contributes to a variation in the extractive content of a sample of any particular wood.

The extraneous substances (resins, gums, kinos, &c.) occurring in the wood are usually isolated with the lignin when the wood is treated with strong acids. Preliminary purification with benzene-alcohol mixture is intended to remove these materials. In the case of jarrah, it was found that very little (1 per cent.) was removed by this solvent, and this was also demonstrated by the microscopic examination of thin cross and tangential sections which had previously been treated in this way. The extraneous material filling the vessels, rays, wood parenchyma cells, and lumina of the fibres remained untouched (see Figures 2 and 3). On microscopic examination, this material was found to remain with the lignin when the section was treated on a slide with 72 per cent. sulphuric acid (see Figure 4).

On the examination of sections of hemlock and spruce, it was found that they also contained a small proportion of material in the ray cells, which was insoluble in benzene-alcohol (see Figures 8 and 9 (hemlock)

TABLE I.—*Results showing the Influence of weak Sodium Hydroxide Solutions on the apparent Lignin Value.*

Species.	Strength of Sodium Hydroxide Solution.	Wood Extracted with Sodium Hydroxide at 98–100° C. for Periods of												Wood extracted with Benzene-Alcohol.	
		20 minutes.		40 minutes.		60 minutes.		80 minutes.		160 minutes.		320 minutes.		(2 : 1)	
		Soluble.	Lignin.	Soluble.	Lignin.	Soluble.	Lignin.	Soluble.	Lignin.	Soluble.	Lignin.	Soluble.	Lignin.	Soluble.	Lignin.
		%	%	%	%	%	%	%	%	%	%	%	%	%	%
Canadian Hemlock ..	N/20	8.7	27.3	9.5	26.9	10.1	26.7	10.6	26.5	11.6	26.5	13.4	26.0	2.2	30.1
	N/8	10.1	26.8	11.6	26.5	12.8	26.5	13.7	26.4	16.9	25.8	19.8	25.6		
	N/4	10.8	26.9	13.2	26.5	14.8	26.1	16.9	26.1	19.5	25.6	22.7	25.4		
Canadian Spruce ..	N/20	6.7	25.7	7.6	25.7	8.2	25.6	9.0	25.1	10.2	25.2	11.6	24.9	0.9	28.4
	N/8	8.3	25.7	10.1	25.1	11.6	24.8	13.0	24.8	15.4	24.5	18.4	23.8		
	N/4	9.2	25.5	11.8	25.3	13.8	24.9	14.6	24.9	19.3	24.3	21.8	23.3		
Jarrah (*E. marginata*)	N/20	..	..	30.8	25.3	31.9	24.9	31.7	24.7	32.8	21.5	33.8	23.9	0.9	50.6
	N/8	..	..	34.3	23.7	25.7	22.8	37.2	21.7	38.6	20.9	40.1	19.7		
	N/4	..	..	37.2	21.8	38.4	20.9	39.5	20.5	41.0	19.8	42.7	18.7		
Red Ironbark (*E. sideroxylon*)	N/8	33.8	21.7	35.2	20.9	35.5	20.7	36.1	20.5	37.3	19.8	38.4	19.0	5.6	42.3
Mountain Ash (*E. regnans*)	N/8	15.8	22.1	16.5	21.7	17.7	21.5	18.0	21.4	19.1	21.1	20.6	20.5	2.3	28.1

Note.—The percentages are expressed on the oven dry weight of the original sample.

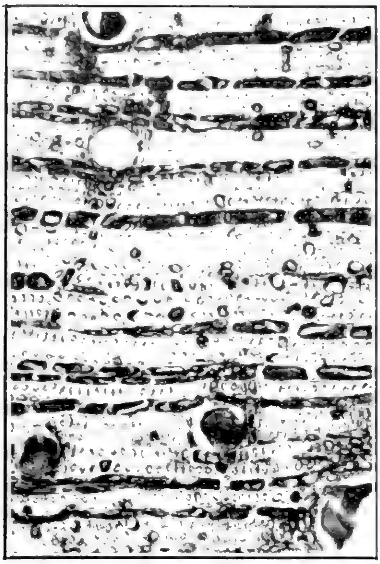

Fig. 2

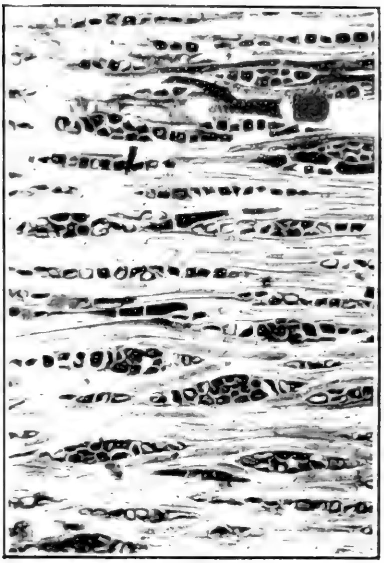

Fig. 3

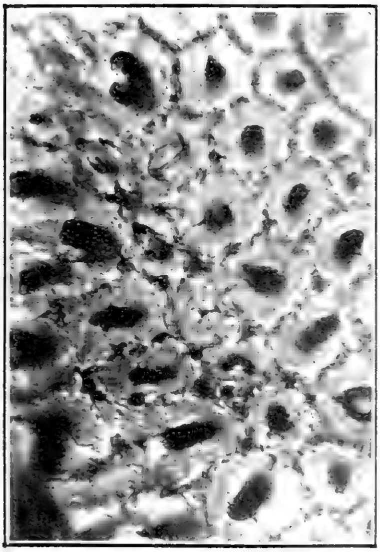

Fig. 4

Fig. 5

FIGS. 2 and 3.—Cross and tangential sections of jarrah after extraction with benzene-alcohol (2 : 1) showing the presence of extraneous material in rays, vessels, parenchyma, and wood fibres. × 75.

FIG. 4.—Cross section of jarrah which has been extracted with benzene-alcohol (2 : 1) and subsequently treated with 72 per cent. sulphuric acid. The extraneous material which existed in the lumina of the wood fibres can be seen to remain with the lignin. × 335.

FIG. 5.—Tangential section of jarrah which has been treated with N/20 sodium hydroxide for 80 minutes. That the extraneous material has not been completely removed by this treatment can be seen. × 75.

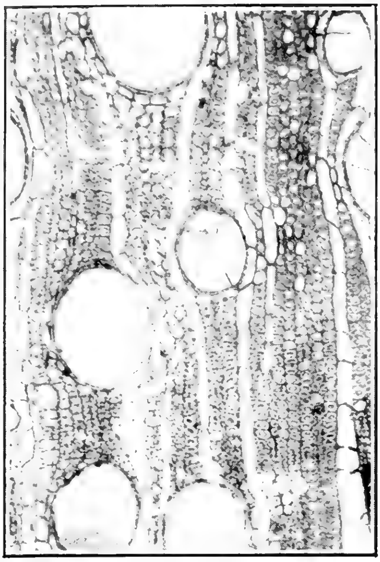

Fig. 6

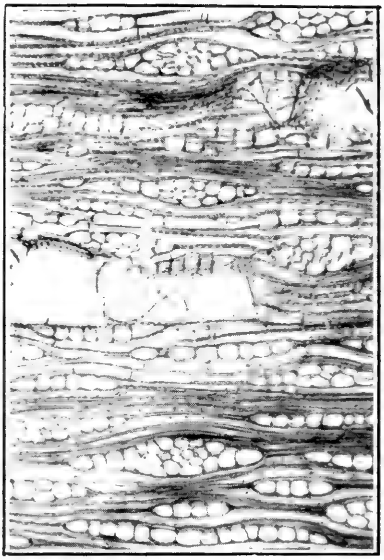

Fig. 7

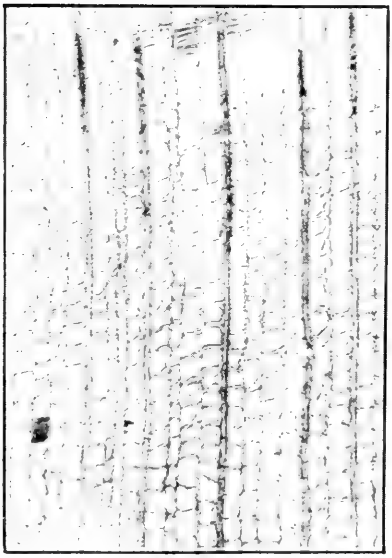

Fig. 8

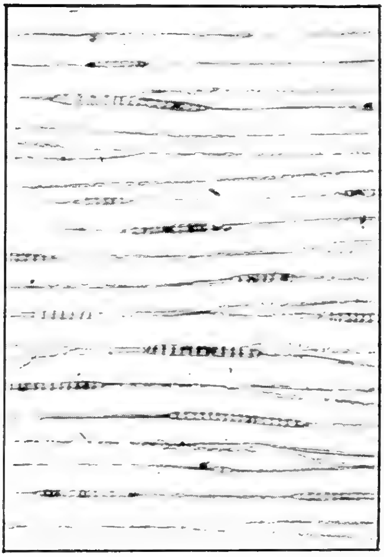

Fig. 9

FIGS. 6 and 7.—Cross and tangential sections of jarrah after treatment with N/8 sodium hydroxide for 80 minutes. It will be noted that all of the extraneous material has been removed, and that there is no apparent alteration of the wood structure. × 75.

FIGS. 8 and 9.—Cross and tangential sections of hemlock after extraction with benzene-alcohol (2 : 1) showing material still present in the rays. × 75.

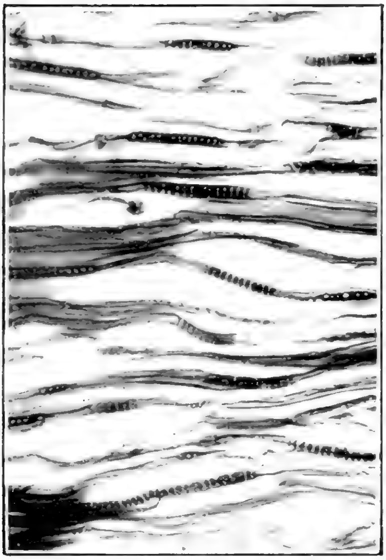

Fig. 10

FIG. 10.—Tangential section of hemlock which has been extracted with benzene-alcohol (2 : 1) and subsequently treated with 72 per cent. sulphuric acid. The material which occurred in the rays is seen to remain with the lignin. × 75.

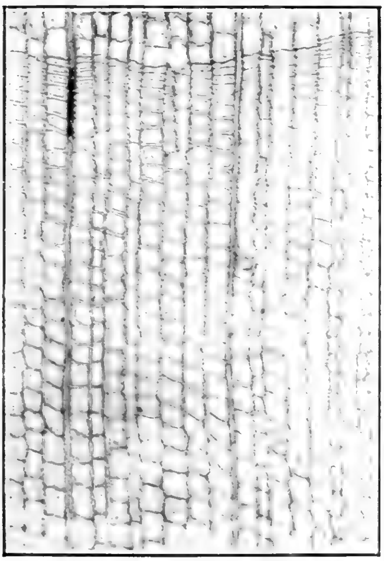

Fig. 11

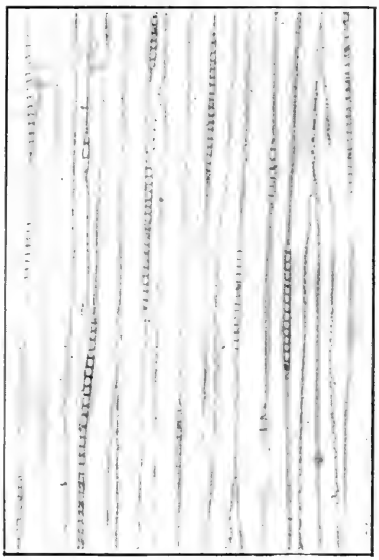

Fig. 12

FIGS. 11 and 12.—Cross and tangential sections of hemlock after treatment with N/8 sodium hydroxide for 80 minutes. The greater proportion of the material which existed in the rays has been removed, and no alteration in the wood structure is apparent. × 75.

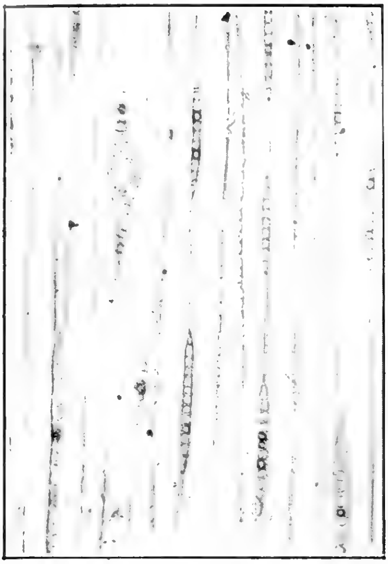

Fig. 13

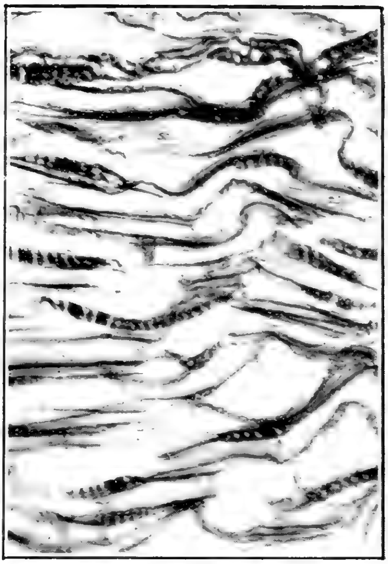

Fig. 14

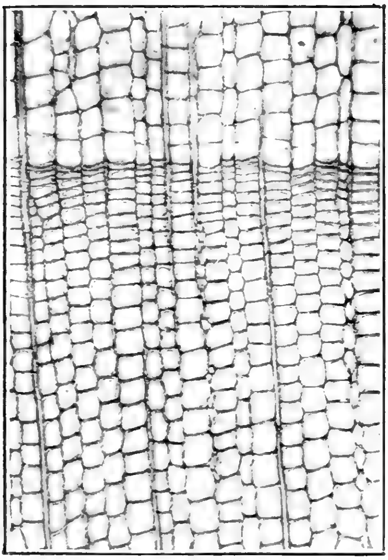

Fig. 15

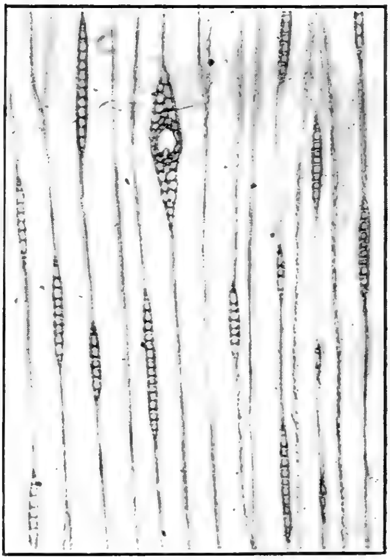

Fig. 16

Fig. 13.—Tangential section of spruce after extraction with benzene-alcohol (2 : 1), showing material still present in the ray cells. × 75.

Fig. 14.—Tangential section of spruce which has been extracted with benzene-alcohol (2 : 1) and subsequently treated with 72 per cent. sulphuric acid. The material which occurred in the rays is seen to remain with the lignin. × 75.

Figs. 15 and 16.—Cross and tangential sections of spruce after treatment with N/8 sodium hydroxide for 40 minutes, showing the absence of material from the rays and no alteration of the wood structure. × 75.

and 13 (spruce)), and which remained with the lignin on treatment with 72 per cent. sulphuric acid (Figures 10 (hemlock) and 14 (spruce)). While this material is not considerable in the case of these softwoods, there are such large quantities of it distributed throughout the wood elements of the various species of the genus *Eucalyptus,* that it becomes a serious factor; and hence the need for eliminating it before estimating the lignin. The above results have led to the opinion that benzene-alcohol is not a suitable reagent for purifying the wood powder.

Tests have shown that other organic solvents and some neutral salt solutions are ineffective in that they only partly remove the extraneous substances. Following this, alkaline solutions were found to be more satisfactory. Of these, weak sodium hydroxide solutions gave the most promising results, because they removed the material with no apparent attack on the wood structure. This was demonstrated by examination of thin sections of hemlock, spruce, and jarrah after treatment with the various strengths of sodium hydroxide according to the method outlined above. The weakest solution used (N/20) did not remove the material within a reasonable time. Figure 5 shows the material to be still present in rather large quantities in jarrah after 80 minutes treatment at 100 deg. C. The N/8 sodium hydroxide solution, however, dissolved practically all of it in the same time (see Figures 6 and 7).

The N/8 sodium hydroxide solution removed the material from the rays of spruce and hemlock, after 40 minutes treatment in the case of the former, but at least 80 minutes was necessary in the latter case. (See Figures 15 and 16 (spruce) and 11 and 12 (hemlock).) A close examination of all treated sections did not reveal any evidence of attack on the wood structure by the sodium hydroxide solutions.

In order to demonstrate quantitatively whether or not lignin is removed by prolonged alkali treatment, the extraction of the wood powder with three strengths of sodium hydroxide, namely, N/20, N/8, N/4, was carried out for the different time intervals mentioned above. The extracted wood was subsequently analyzed for lignin, which was calculated back to the oven dry weight of the original wood. The maximum time of extraction (320 minutes) was considered sufficient for all practical purposes. These conditions were applied in the first place to hemlock, and it was found that there was an immediate solution of material in the sodium hydroxide amounting to approximately 10 per cent., after which the amount of extraction gradually increased with time and strength of alkali. (See Table 1 and Diagram 1.) It may be argued that the latter is due to a solution of lignin, but it is more probable that part of the cellulose and the pentosans are being slowly hydrolyzed. The difference in apparent lignin content after 20 minutes extraction with sodium hydroxide from that after benzene-alcohol treatment (see Table 1) is not regarded as due to loss of lignin, but rather to the fact that extraneous materials otherwise isolated with it have been removed by the alkali. The facts (i) that, after 320 minutes extraction, the apparent lignin content is very little different from that after only 20 minutes extraction (see Table 1), and (ii) that this is the case for each of the three strengths of alkali used, are taken as indicative that there has been no loss of lignin. These points are clearly demonstrated by the curves in Diagram 1. The slight decrease in apparent lignin found when the extraction with alkali was continued for periods longer than 20 minutes was due to the isolation with the lignin in the latter case of small amounts of extraneous materials which existed in the rays of the wood, and which resisted to a certain extent the action of the alkali. This has been substantiated by the microchemical work with thin sections, when it was found that at least 80 minutes extraction with N/8 sodium hydroxide was necessary to remove all the extraneous material (see Figures 11 and 12), although by far the greater part was removed after 20 minutes. The effect of the alkali on the lignin must, then, be considered to be very slight even when N/4 sodium hydroxide is used.

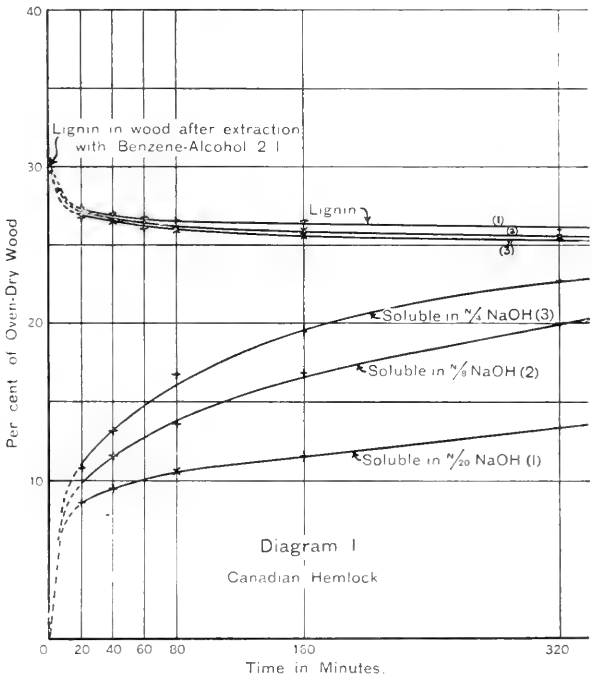

DIAGRAM 1.—Showing (i) the progress of extraction when hemlock is treated with N/20, N/8, and N/4 sodium hydroxide for different periods; and (ii) the lignin content of the extracted wood based on the oven dry weight of original wood.

When similar experiments were applied to spruce wood powder, the results obtained were found to substantiate the conclusions drawn from the results of the experiments with hemlock (see Table 1 and Diagram 2). These results again indicated that lignin isolated from wood powder which has only been purified with benzene-alcohol was contaminated with extraneous material which, as in the case of hemlock, amounted to about 3 per cent. of the oven dry wood. Microchemical studies of thin sections of this wood showed that the extraneous material was readily removed by the alkali, very little remaining after 40 minutes treatment with N/8 solution (see Figures 15 and 16). The lignin curves obtained when N/20 sodium hydroxide was used to purify both hemlock and spruce wood, were found to remain flat after 80 minutes treatment. On this evidence alone, the N/20 solution would have been selected for the purification, but microchemical examinations showed that it was not strong enough to remove all the extraneous material within a reasonable time.

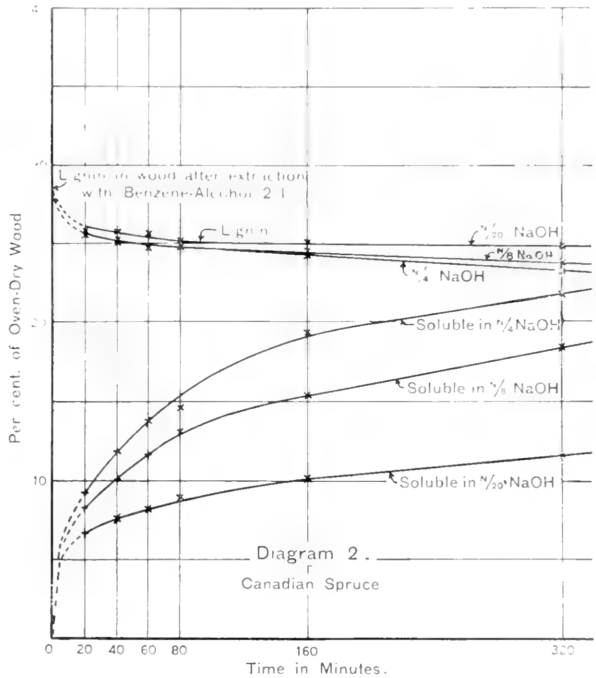

DIAGRAM 2.—Showing (i) the progress of extraction when spruce is treated with N/20, N/8, and N/4 sodium hydroxide for different periods; and (ii) the lignin content of the extracted wood based on the oven dry weight of original wood.

When this quantitative study was extended to jarrah, it was found that the material dissolved by sodium hydroxide amounted to over 40 per cent., whereas in spruce and hemlock it did not greatly exceed 20 per cent. even after prolonged extraction with solutions as concentrated as N/4. The greater part, representing the free material, was practically dissolved in the first 40 minutes, and after 80-120 minutes the rate of extraction became slower and more uniform (see Table i and Diagram 3). Concurrently, the apparent lignin was found to be greatly reduced in the initial stages of treatment and rapidly approached a constant value. In other words, it was reduced from 50.6 per cent. in the benzene-alcohol extracted wood to less than 25 per cent. in the wood extracted with sodium hydroxide for 20-40 minutes, and after 80 minutes extraction it decreased but slowly. On the evidence of the microchemical studies, it was obvious that the early treatment removed all the free extraneous material, that the solution proceeded but at a decreasing rate as the sodium hydroxide penetrated the fibre bundles, and that the slow decrease of apparent lignin in the later stages was due to the gradual solution of the material from within the lumina of the fibres.

The premature flattening of the lignin curve during the extraction of the wood with N/20 sodium hydroxide requires some explanation. During the extraction of hemlock with the N/20 solution, it was found possible to determine the approximate consumption of alkali, which was 140 to 150 cc. per gram of soluble material. Anticipating only 30 to 35 per cent. extraction with jarrah, it was considered that 150 cc. of the N/20 solution would suffice to extract 3 grams of wood powder. However, the quantity of extractives present proved to be greater (over 40 per cent.) than originally thought, and consequently the rate of extraction with this solution was retarded, the total remaining at 33 to 35 per cent. Hence the apparent lignin content remained

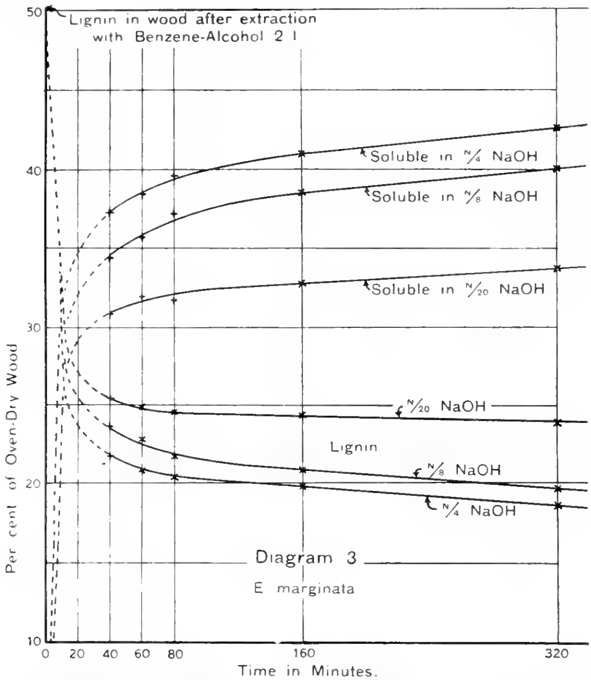

DIAGRAM 3.—Showing (i) the progress of extraction when jarrah is treated with N/20, N/8, and N/4 sodium hydroxide for different periods; and (ii) the lignin content of the extracted wood based on the oven dry weight of original wood.

constant on account of the failure of the N/20 solution to complete the removal of extraneous matter. The results from these experiments with jarrah suggested that it would be necessary to use the N/4 strength of sodium hydroxide to purify the wood completely. However, it was recognized that the sample examined was an extreme case, as it contained such a large amount of extraneous material—a quantity of which existed in the lumina of the wood fibres—that it was difficult to remove. It was decided that in such cases it would be preferable to tolerate a slight contamination of lignin, as, for example, after 80 minutes extraction with the N/8 solution, rather than risk a degradation by the use of stronger solutions over a longer period in order to remove all traces of extraneous matter.

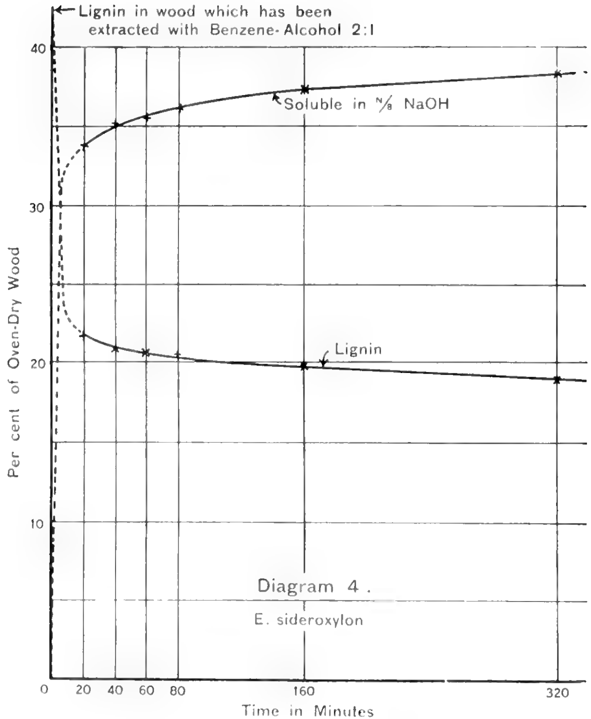

DIAGRAM 4.—Showing the effect of the treatment with N/8 sodium hydroxide for different periods on red ironbark.

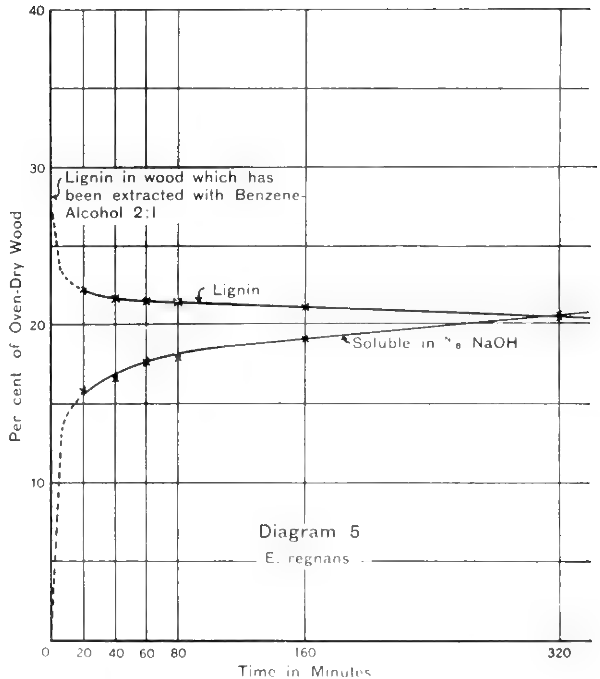

DIAGRAM 5.—Showing the effect of the treatment with N/8 sodium hydroxide for different periods on mountain ash.

The procedure was further applied to samples of red ironbark and mountain ash, using only the N/8 solution of sodium hydroxide. The results obtained indicated clearly that with these two widely different species (the red ironbark being representative of a group of dense red woods, and the mountain ash of a group of open-grained pale-coloured woods), the treatment for a period of 80 minutes was all that was necessary to obtain uncontaminated lignin. (See Table 1 and Diagrams 4 and 5.)

The experiments indicated that the wood powder, purified by means of alkali, was more likely to give constant lignin values for a species when the results are calculated on the basis of extractive-free wood. The extractives are known to vary widely within a species, and therefore would directly and indirectly influence the lignin value determined by any procedure when it is calculated on the oven-dry basis.

6. Conclusions.

On the evidence obtained, a new procedure for the determination of the lignin content of wood is recommended. This requires the preliminary purification of the wood powder with N/8 sodium hydroxide for 80 minutes at 98 deg. to 100 deg. C. Weaker solutions are not recommended because of their failure to remove all the extraneous material in a suitable time, and stronger solutions (up to N/4) are avoided because the results for lignin when they are used agree substantially with those obtained when the N/8 solution is used, and, in addition, the possibility of attack on the wood structure is reduced.

One hundred (100) cubic centimetres of the reagent per 3 grams of the air-dry wood should be sufficient for all samples. In certain of the latter, which contain large amounts of extraneous material, it will be necessary to aid the reaction by agitation, and this latter procedure is recommended for all cases. Treatments for periods of longer than 80 minutes are not suitable for laboratory routine methods, and may, in addition, cause complications through attack on wood structure. The possibilities of this method as applied to other hardwoods have not been investigated, but it is considered that the purification of the wood by the use of alkalies is much preferable to the employment of organic solvents, because the final lignin product is less likely to be contaminated with extraneous substances. The experiments with spruce and hemlock indicate that the alkali method of purification gives a purer lignin residue than the benzene-alcohol method. While in a number of cases the contamination is not sufficient to affect comparative analyses to any degree, the lignin which is isolated for constitution studies needs to be as near true lignin as is possible, and the alkali purification might assist towards this end. The doubt still existing in the minds of many workers as to the ultimate effect of the alkali on the lignin seems unwarranted when the lignin curves for hemlock and spruce (Diagrams 1 and 2) are considered. In these two cases, prolonged extraction with N/4 alkali does not remove lignin, and the very gradual slope of the curves has been caused by the removal of extraneous substances from the ray cells. The difference between the apparent lignin content of wood purified with benzene-alcohol and of that of wood purified with the alkaline solutions has been definitely shown to be due to extraneous material that is not soluble in benzene-alcohol.

This investigation became necessary owing to the failure of the existing standard procedure when applied to Australian woods. It is considered, however, that the method may prove of value to other workers in the field of wood chemistry. The work will not be complete until the nature of the substances that are removed by the alkaline treatment, together with the extraneous substances, is determined, and this will be considered at some future date as time permits.

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COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

Refrigeration Applied to the Preservation and Transport of Australian Foodstuffs

A Survey and a Scheme for Research

By

J. R. VICKERY, Ph.D.

MELBOURNE, 1931

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PAMPHLET No. 23.

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CONTENTS.

FOREWORD.

At the first meeting of the Council, held in June, 1926, it was decided that efforts should be concentrated primarily on the organization of research work on certain main groups of problems, of which groups "The preservation of foodstuffs, especially cold storage," was one. Owing largely to the lack of the necessary trained investigators, it has not so far been practicable for the Council to proceed with the organization of a special "Division" to undertake work on these problems, as it has done in the case of the other main groups on which it was decided that efforts should be concentrated.

As indicated in its Annual Reports and other publications, the Council has been able to arrange during the past few years for investigations to be conducted on certain important cold-storage problems, such as the preservation of citrus fruits, the maturation and transport of bananas, and the freezing of beef. In the meantime, the Council has continually recognized that the whole question of undertaking systematic investigations in this field of work is a matter of very considerable importance to Australia's primary industries, in connexion with the export of perishable foodstuffs, and with the development of land settlement and the problem of finding new markets.

With the recent return to Australia of Dr. J. R. Vickery, who for the last four years has been at the British Low Temperature Research Station, Cambridge, as an officer of the Council and also as an 1851 Exhibition Research Scholar, the Council has now decided to proceed with the creation of a Section of Food Preservation, and to place him in charge of it. Owing to the present financial stringency, it will not be practicable yet to develop the work of this Section on such a wide basis as had previously been contemplated. The Council has, however, received from various sources offers of co-operation and assistance in investigations on various problems relating to the preservation and transport of foodstuffs, and it will thus be able to make a beginning with the work of the new Section on an effective though limited scale.

As a preliminary to the establishment of the Section, the Council obtained from Dr. Vickery a report, which is printed in this pamphlet. In making it available, the Council desires to indicate that such action does not mean that the opinions expressed in it are necessarily its adopted views, nor that it is intended to follow in their entirety the recommendations made.

SUMMARY.

A survey has been made of several primary industries in which refrigeration is necessary for the successful preservation and transport of the foodstuffs concerned. The main purpose of this survey was to obtain information for the preparation of a programme of the most urgent scientific investigations required in this field; the investigations would be directed chiefly toward the development of methods of placing the foodstuffs on the overseas markets with a minimum of wastage and in a condition resembling, as closely as possible, that of similar, fresh food.

It is recommended that investigations be carried out in Queensland with the view to testing the possibilities of exporting hindquarters of beef in the chilled condition. Further investigations required in the field of meat products include:—

(*a*) the freezing, storage and thawing of bacon pig carcasses with a view to placing them in the hands of curers overseas in a condition most suited to the production of bacon and hams of good quality.

(*b*) the freezing and storage of edible offal.

Attention is drawn to the extensive wastage occurring in exported apples and pears, and the consequent severe monetary losses sustained by exporters. Since few exact data exist in this important branch of our exports, it is recommended that extensive investigations be commenced on three aspects of the storage and transport of apples and pears, viz., orchard conditions affecting the subsequent "life" of the fruit, the influence of conditions of transport and storage, and the complementary biochemical studies designed to determine the relationships between the physical and chemical constitution of the fruit and its storage-life.

It is urged that investigations on navel oranges and passion fruit already being carried out by the Council be continued and extended. Investigations directed toward increasing the number of varieties of grapes now exported and toward their safer transport overseas, should be commenced.

Two urgent problems in the interstate transport of fruit await solution, namely, the carriage of tropical fruit to the south and the carriage of apples and pears from Tasmania to the northern States.

For several types of foodstuffs, notably lamb, fish and tropical fruit —excluding bananas—scientific investigations will probably be required in the near future.

It is suggested that efforts be made to secure the study of refrigerated transport on ocean-going vessels by means of an Empire Refrigeration Transport Survey Team to which an Australian investigator would be seconded.

Two laboratories, with attached cold storage facilities, should be established in Brisbane and Melbourne, the former to study problems in meat export trade and in the transport of tropical fruits, and the latter to investigate the preservation and transport of non-tropical fruits.

An organization suitable for the co-ordination of these and future investigations is outlined.

The Preservation and Transport of Australian Foodstuffs by Cold:

A Survey and a Scheme for Research.*

1. Introduction.

Both to gain an adequate picture of the various industries employing refrigeration for the preservation and transport of foodstuffs, and to determine where the application of scientific research would most likely aid in placing the refrigerated products on the various interstate and overseas markets in a condition resembling, as closely as possible, that of similar fresh food, I have visited the four States, viz., New South Wales, Victoria, Queensland, and Tasmania, where these industries are most firmly established, and deal with a wide range of foodstuffs.

During the course of the investigation, inquiries have been made concerning the chief aspects of the meat export and fishing industries, the production and export of fresh fruit and dairy produce, and general problems relating to the intra-state, interstate and overseas transport of foodstuffs under refrigeration. The inquiry necessitated a survey of pastoral, farm, and orchard conditions, a study of meat works, fruit-packing sheds, and the methods of loading, stowing, and cooling the produce in insulated railway wagons and ships' insulated holds. In the case of the fishing industry, inquiries were made concerning the amounts of fish obtained from the chief fishing grounds, the potentialities of the chief types of fish obtained, and the present methods of the transportation, preservation, and distribution of the fish.

Opportunity was taken everywhere to obtain the views of pastoralists, farmers, orchardists, engineers, technicians, and business men concerned in all phases of these industries, and those of many officers of the State Departments of Agriculture.

For the sake of clarity, it will be convenient to deal with the economic aspects, the research work previously carried out, and the chief scientific investigations required under the headings of:—

(1) Meat,
(2) Fish,
(3) Dairy produce,
(4) Fruit,
(5) Refrigerated transport,

together with the organization required.

2. Meat Products.

(i) *Beef.*

Although Queensland has always occupied the premier position in the export of beef from Australia, New South Wales and Victoria, in the past, contributed considerable quantities. To-day, however, 90 per cent. (approximately) of the beef (as quarters) exported from Australia is produced in Queensland, the remaining 10 per cent. being divided between Western Australia (Wyndham) and New South Wales. The

* Received for publication 16th September, 1931.

supplies of beef cattle in Victoria and New South Wales are barely sufficient to meet the demands of the local markets, and it is unlikely that, in the future, the raising of fat cattle for export from these States can be carried out at a cost comparable with that in the less closely settled areas of Northern Australia.

Taking the world production as a whole, unlike most other primary produce, there has been no increase, but on the other hand, perhaps a decrease, in the production of beef during the last five years. The supplies from the Argentine seem gradually to be dwindling, owing chiefly to the spread of more intensive cultivation on the rich black soil plains forming the main cattle fattening areas. Uruguay shows no signs of increasing her production of beef, but there are distinct signs that, in the future, the Southern States of Brazil will attain approximately to the production of the Argentine. It is to be expected, therefore, that, taken as a whole, the supplies of beef from South America will show no marked decrease.

The grading-up of the herds, eradication of stock diseases, and the improvement of the pastures, are gradually improving both the quality and numbers of South African and Southern Rhodesian cattle, and already several successful exports of live cattle from Southern Rhodesia to England have taken place. It is difficult, however, to predict the extent of the future development of an export trade from these countries, but I am inclined to believe that the amazingly rapid commercial expansion and spread of western civilization in Central Africa will absorb the bulk of the increased production of the African ranches. For instance, the large mining areas of Northern Rhodesia are, at present, solely dependant on Southern Rhodesia for their supplies of meat.

Canada has a small surplus production of cattle, the bulk of which was formerly sent to the United State of America. Recent tariff enactments by the United States of America have greatly reduced this trade, and Canada has now re-commenced the export of live cattle to Europe. Again, it is doubtful whether Canada can greatly increase her supplies or produce cattle at a price to compete with South America.

The low prices of beef now prevailing overseas are an indication of a world-wide reduced standard of living, rather than of an over-production of beef. In fact, Germany and the United States of America are definitely suffering from a shortage of beef. In the United States of America, in particular, the numbers of cattle have remained practically constant at about 56,000,000 head during the last few years, and therefore the ratio of cattle to the human population bears a decreasing value.

To some extent, the apparent world shortage of beef is offset by the increased production of mutton and lamb; for instance, there are indications that cheap mutton is tending partially to displace beef as the chief meat diet of the English working classes. Over the five-year periods 1921-1925 and 1926-1930, the exports of lamb and mutton from the chief exporting countries—New Zealand and the Argentine—have shown a definite increase.

On the whole, therefore, Australia should retain, and possibly increase, the volume of her exports of beef, *provided that she can supply it to the consumers overseas in a condition most suited to their needs.*

At the present time, only about 25 per cent. of the total imports of beef into Great Britain are received in a frozen condition, while of the total exports from the Argentine, Uruguay, and Brazil, the proportions of chilled to frozen beef respectively are approximately 3:1, 2:1, and 2:1. An idea of the preference in Great Britain for the chilled article may be gained by quoting the wholesale prices now prevailing (August, 1931) for imported hindquarters of beef, viz., 6¾ to 7¼d. per lb. for Argentine chilled, and 3d. to 3¾d. per lb. for Australian frozen, while the average difference in prices prevailing during the last few years has been of the order of 2d. per lb. A smaller discrepancy exists between chilled and frozen forequarters. Not only are the prices for Australian beef extremely discouraging to the Queensland pastoralist, but, even at these low figures, beef is very difficult to sell, the chief outlets being by contracts for the military and naval forces and public institutions, very little, except in the warm summer months, passing into general retail trade. While the lower prices and poorer demand for the Australian frozen article may be attributed in part to the fact that it has a lower average initial quality than Argentine beef, it is to be largely accounted for by the fact that the British consumer now recognizes that chilled beef resembles the fresh home-killed article more closely.

In order to maintain the outlet for excess beef produced in Queensland, inquiries should be made into the possibility of exporting beef in a condition more closely resembling that of the fresh, unfrozen material. The only methods appearing feasible are the export of:—

(*a*) Quick-frozen quarters or cuts of meat,
(*b*) Chilled quarters.

The long-continued, careful investigations carried out by the joint Meat Preservation Committee of the Council and of the Australian National Research Council have failed to indicate any method whereby whole quarters may be quick-frozen, and after storage and thawing, present a condition closely resembling that of fresh beef. An export of quick-frozen packaged cuts of beef may be feasible, but it appears likely that, for some time to come, the technical difficulties, the difficulties of disposing of the poorer cuts of meat, and the high costs of production, will prevent the general adoption of this process. The most hopeful line of investigation, therefore, would appear to be the possibility of exporting hindquarters in the chilled condition. The small, constant difference in price between chilled and frozen crops (forequarters) is insufficient to warrant the probable extra cost of transport involved in exporting them in the chilled condition.

Experiments carried out at the Low Temperature Research Station, Cambridge, during the last two years, have defined approximately the chief causes of spoilage, showing bacterial and fungal attack of the fat to be the most important cause. There are indications that regulation of the initial rate and extent of evaporation of moisture from the quarters of beef may provide a useful method of control of this and other types of microbial spoilage, and, indeed, when conditions were arranged in the Cambridge experiments for a fairly high initial rate of evaporation of moisture, the quarters of beef were unaffected by storage for a period of 60 days. These experiments are distinctly encouraging, since the maximum period of storage in the chilled condition to be allowed for in possible exports from Queensland is of the order of 55 days.

One of the essentials of a trade in chilled beef being regularity of supplies, the question thus arises as to whether sufficient continuous supplies of young beef of good quality could be obtained in Queensland. The low prices of frozen beef and the relatively high costs of production prevailing during the last few years have provided little inducement to the pastoralists to raise, or even maintain, the quality of their herds by the purchase of high-grade bulls. It is agreed that, as a whole, considerable decrease in the average quality of beef exported from Queensland has taken place, and that the pastoralists have not altered or have been unable to alter the type of beast to supply the short-backed, chubby carcass having a large proportion of flesh to bone.

Queensland may be divided arbitrarily into Northern and Central-Southern districts by a line running east and west, represented by latitude 22° S. Inquiries made in the Northern district showed that, on the whole, a very marked decrease in the quality of the beef had taken place during recent years. The climatic conditions prevailing in the Central, Gulf, and Western country make it almost impossible to prepare the cattle for slaughter before an average age of five to six years. The period during which supplies are available for the freezing works at Townsville is limited merely to fifteen weeks. This area is largely unsuitable for sheep, and, for many years to come, must remain chiefly a cattle producing area; but the prospects of obtaining relatively regular supplies of young beef of good quality are unfavorable. It is chiefly to the Central and Southern districts, therefore, that we must look to obtain adequate supplies of beef suitable for export in the chilled condition. On the whole, the quality of the cattle produced in this area is higher than that of the North. A number of fine studs of cattle of types suited to modern requirements exist in this area, and the pastoralists believe that, given sufficient inducement to "grade-up" the herds, a steady improvement, from the point of view of breeding, could be instituted. At the present time, the districts yielding the most regular supplies of fat cattle are situated in the coastal belt, which may be taken as extending to the limits of the western ranges, some 200 miles inland. In the years of good rainfall, excellent fattening areas occur also in the far west and south-west, where the flooding of the Georgina, Diamantina, and Cooper's Creeks provides rich pastures, but drought conditions are so frequent in these areas that their supplies of fat cattle are likely always to remain irregular in volume.

At present, the pastoralists in the coastal belt rely on the summer rains to provide sufficient pastures for the fattening period from February to July, and, if good winter rains fall, a further supply of fat cattle is available for slaughter during September and October. Gradual improvements for fattening are being made in the pastoral properties by the elimination of surplus timber, subdivision into smaller paddocks, and the provision of a larger number of water-holes. If better prices for beef were given, the pastoralists believe that, by the extension of these practices, fat cattle could be regularly supplied to the meat works from February to November, and that cattle could be fattened at an average age of three years instead of four to five years as at present. It is the opinion of the leading men in the pastoral industry that no methods of fattening other than those utilized at present are likely to be practicable. It is doubtful, however, whether the above methods would ensure a sufficiently regular and adequate volume of fat cattle during the period from August to November. Further, there is evidence to support the view that the utilization of considerable areas of the existing well-watered coastal areas and the reclaimed prickly pear country for the intensive fattening or "topping-off" of cattle, is not impracticable.

Experiments on the sowing of pasture grasses and cover crops on reclaimed prickly pear lands have recently been carried out by the Queensland Department of Agriculture at Palardo, South-Central Queensland, and have been described by H. C. Quodling. [*Queensland Agric. Jour.* **34**; 513, 1930.] The soil in this district, which has a rainfall of about 21 inches per annum, is dark-red heavy loam, and has been covered with a fairly dense growth of small trees. In this district, the pear had once covered an area of considerably more than 1,000,000 acres. These experiments have shown quite clearly that good stands of lucerne, pasture grasses such as Rhodes and Prairie, and cover crops, such as wheat, oats, and barley sown simultaneously, could be grown on this reclaimed land, which could carry and fatten approximately one ox per 3 acres all the year round. It is believed that, provided the price given for beef were of the order of 26s. per 100 lb. dressed weight (the present price is approximately 18s. to 20s. per 100 lb.), the sowing of very considerable areas with similar pasture grasses and cover crops, not only in the south-central district, but also nearer the coast, would yield profitable returns to small graziers, who could fatten store cattle purchased from the larger runs.

It may be argued that land capable of carrying the relatively heavy pastures indicated in these experiments would be used for dairying, the raising of fat sheep and lambs, and wheat-growing. While these possibilities exist, nevertheless, the world production of beef does not seem likely in the future to keep pace with the production of dairy produce, fat lambs, &c., all of which are now being produced on an ever-increasing scale. Consequently, the raising of fat cattle on such improved areas would seem to be a profitable and logical method of utilizing the land.

Summing up the situation, therefore, it would seem that fairly ample supplies of fat young cattle could be made available for export as chilled beef from the central and southern districts* during the months February to August inclusive, and it is likely that the stimulus of better prices to be realized from an export of beef in the chilled condition, and the provision of better fattening areas, would later make available supplies of cattle during the period from August to November.

Of the five meat works situated in the central and southern districts (eight beef export works are now operating in Queensland), four works, treating 65 to 70 per cent. of the beef exported from Queensland, viz., Gladstone, and the three Brisbane works at Cannon Hill, Pinkenba, and Moreton, have their own wharves for direct loading into overseas vessels. They appear, therefore, to be admirably situated for dealing with the export of so perishable a product as chilled beef.

All the evidence obtainable from a consideration of the research work already carried out on chilled beef, the survey of Queensland's cattle industry, and the situation and equipment of certain meat works, points strongly to the need for the initiation of investigations into the possibility of transporting Australia's beef in the chilled condition overseas.

* These districts at present contain approximately 67 per cent. of the total cattle of Queensland. The well-watered coastal pastoral districts where, it is believed, less haphazard methods of fattening could be utilized, now contain approximately 55 per cent. of Queensland's cattle.

Little reference has been made to the participation of the Northern Territory and North-west Australia in this possible development. The cattle industry in these regions must remain for many years the chief mode of primary production. Moreover, the fact that the meat works at Wyndham and Darwin (now closed) are situated nearer to the British markets than Brisbane by a distance equivalent to one week's voyage, would naturally give this area some advantage if the export of chilled beef were possible. It is doubtful, however, whether sufficient regular supplies of young fat cattle would be available for some time to come, and the possible difficulty of obtaining regular shipments would probably be a very considerable obstacle to the export of chilled beef from these areas. It should also be borne in mind that the results of experiments carried out in Queensland would, with modifications, be applicable to North-western Australia.

(ii) *Lamb and Mutton.*

During the two years 1928-29 and 1929-30, 1,495,845 and 2,132,738 carcasses of lamb respectively, and 728,756 and 786,497 carcasses of mutton respectively were exported from Australia, Great Britain absorbing the bulk of the consignments. While these figures do not show any substantial increase on the averages of the exports for the last ten years, there are indications that Victoria and New South Wales will shortly be exporting larger numbers of lambs, and it is probable that Tasmania and Western Australia will soon be in a position to contribute substantial amounts to the total exports. Observations made in Victoria and New South Wales have shown that no outstanding faults exist in the treatment which the carcasses of lamb receive during the chain of treatment from slaughter to the wholesale markets of Great Britain; in general, the chief problem confronting Australia in this branch of meat export is the improvement in the average initial quality of the carcasses.

The reason for the fact that the average price received for Australian lambs is lower than that received by New Zealand appears to be due chiefly to the lower average quality of the Australian carcasses, but one cannot neglect also the factor of the vigorous advertising campaign pursued in Great Britain by New Zealand. Until this improvement in quality is effected, and the average quality of the lambs approaches that of carcasses exported from New Zealand, there would seem to be no object in applying the methods of scientific investigation to the finer points in the chain of treatment.

It cannot be recommended, therefore, that any investigations aimed at improvements in the methods of cooling, freezing, transport, and storage of lamb (and mutton) be undertaken in Australia at the present time. Until attention needs to be paid to these details, the results of the recent scientific survey of the New Zealand lamb export trade* will probably serve, with modifications suited to local conditions, as a guide for improvements in the Australian technique.

(iii) *Pork, Ham, and Bacon.*

Concurrent with the rapid increase in the production of dairy produce in Australia, there has been an increase of production in the associated industry—the raising of pigs. This production fluctuates

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* *Jour. Coun. Sci. Ind. Res., Aust.,* **2**: 245. 1929. The full report of this survey is now in the press.

widely, and, unless the excess during periods of gluts be exported, the prices received by the farmers become so low that the industry suffers a severe reverse. The present production appears to be limited solely by the demand in Australia, and, given sufficient inducement, it appears very probable that the numbers of pigs to be raised even solely in conjunction with the dairy industry could be increased very greatly. The industry, so to speak, is working on part-time production.

Since many of the wheat farmers now realize that it is unsafe to depend for a livelihood solely on one type of produce, considerable numbers of fat pigs will probably be raised in the areas now devoted to the production of grain.

The question of the most profitable method of disposal of Australia's surplus pig-products is now giving rise to considerable discussion in the industry. For a number of years past, relatively small quantities of bacon and frozen pork have been exported to the East, but it is unlikely that these markets can absorb greatly increased quantities. Recently, a considerable quantity (800,000 lb. approximately in 1929-30) of frozen pork has been exported to Great Britain, chiefly from Queensland and New South Wales. While it appears probable that there exists a profitable outlet in Great Britain for increased supplies of frozen pork, the opportunities are not unlimited. Is it possible, therefore, to export green bacon and hams (cured but not smoked) to Great Britain? Since the wholesale prices of good quality Danish green bacon in England are now of the order of 6d. to 6½d. per lb., apart from any technical difficulty in an export trade, it is unlikely that profitable prices could be obtained for Australian bacon and hams.

Experiments recently carried out at the Low Temperature Research Station, Cambridge, have shown that the limiting factor in the storage of green bacon in the frozen condition is the susceptibility of the fat to oxidation, which, in its more advanced stages, produces rancidity; it is probable that, with the present methods of storage and transport available, there would be a considerable incidence of rancidity in the fat of green bacon exported from Australia.

There appears, however, to be a considerable outlet in England for Australian bacon pigs (weighing 120 to 180 lb. per carcass) which could be cured after thawing. Experiments conducted chiefly by the New Zealand Meat Producers' Board have shown that it is possible to manufacture bacon and hams of good quality from frozen carcasses, since the fat of the uncured carcass does not undergo appreciable oxidation during cooling, freezing, and storage for periods up to six months in duration. According to reports received from England, the bacon factories in England, at present, are working at only 25 per cent. of their full capacity, and, even in prior years, when the wholesale price of bacon was higher, the limited supply of cheap pigs greatly restricted their output. Can Australia, therefore, supply frozen bacon carcasses to the English bacon curers at a price payable to the producer? The present wholesale price of Australian bacon pigs in England is approximately, 5d. to 5½d. per lb., and when one considers the cost of curing, the trimming and wastage involved, and the fact that there is a shrinkage of approximately 20 per cent. in weight during curing and smoking, it is unlikely that, with the prevailing low price of Danish bacon, considerable quantities of Australian bacon pigs will be purchased for English curing. There is every reason to believe that the present wholesale prices of bacon in England are definitely unprofitable to the

Continental curers, and that, owing to measures being instituted to restrict Continental production, prices are likely to rise considerably in the near future.

It has been almost impossible to obtain reliable figures for the cost of production of fat pigs in Australia, owing chiefly to the fact that they are usually raised on farm by-products such as skim milk, waste maize and wheat, to which no definite values can be allotted. While farmers, both in Queensland and in New South Wales, stated that the present prices of pork and bacon carcasses ruling overseas did not yield a profitable return, the opinions of the experts on pig husbandry in each State Department of Agriculture were that it was doubtful whether the total costs of production at present exceeded 2½d. to 3d. per lb., a figure which should make export overseas a profitable one, even with the present low prices ruling. Provided we can export bacon carcasses overseas at prices approximately 25 per cent. lower than the ruling wholesale price per lb. for Danish green bacon, a ready demand should exist in England for the cheap Australian raw material.

It behoves us, therefore, to place our bacon carcasses in the hands of the English curers in a condition most suited for the production of bacon and hams of high quality. At present, it is uncertain, however, whether the present technique in the cooling, freezing, storage and thawing of the bacon pigs is such as to fulfil this condition, one of the chief dangers being the possible development of "reestiness" or rancidity in the fat when the bacon is being stored or distributed.

It is suggested, therefore, that the Council undertake an investigation to determine the most suitable technique in the preparation of the bacon pig for the English market.

It is doubtful whether, at the present time, the type of fat pig being produced, particularly in Queensland and New South Wales, is wholly suited to the overseas market. Examination of large numbers of carcasses in these States showed that they had too great a proportion of fat to lean, the external layer of fat usually being excessive. The cause of this unsatisfactory condition lies in the breed and/or the diet of the pigs. In addition, there are many indications, particularly in pigs from the Northern Rivers District of New South Wales and from Queensland, that too soft a fat is laid down, i.e., speaking in chemical terms, it is too highly unsaturated; it is probable that the rate of onset of "reestiness" in such fat is greater than in less unsaturated (harder) fats. It is hoped that the Food Preservation Section will shortly be in the position to indicate the type of fat most suited to withstand the onset of "reestiness" in the bacon. When these data are available it is urged that the Council secure the co-operation of the several State Departments of Agriculture to apply the results of previous investigations, and, if necessary, to carry out new investigations to determine:—

(*a*) The cause of the excessive ratio of fat to lean, and

(*b*) The mode of fattening required to produce the most suitable "bacon fat."

If sufficiently low temperatures during storage and overseas transport could be obtained, it is probable that Australia might be in the position to export green (unsmoked) bacon, although the prevailing high costs of curing would be a serious obstacle. The present difficulties in the way of export, being beyond our control, are so great that it cannot be recommended that, at present, the Council undertake any investigations in the field of curing, freezing, storage, and transport of bacon and hams.

(iv) *Edible and Pharmaceutical Offals.*

In addition to the various select cuts of skeletal muscle—fillet steaks, ox tails, and cheek meats—the frozen organs, such as ox and sheep's sweetbreads, ox, sheep's, and pigs' livers, kidneys and hearts, and ox tripes, also form a profitable part of the export trade from the meat works. While considerable differences exist in the mode of preparing these products for freezing and in their packing at the various works, they are usually frozen in air temperatures ranging from 0° to 10°F.

Examination of Australian edible offal at Smithfield Market, London, from time to time has shown that the quality of the livers and kidneys is distinctly inferior to that of similar, fresh, English offal, an observation supported by the figures for the comparable wholesale prices at these markets. The following table gives the comparable prices of some products during June, 1931:—

PRICES OF ENGLISH AND AUSTRALIAN EDIBLE OFFALS.

Origin.	Ox Livers per lb.	Ox Kidneys per lb.	Sheep's Livers per lb.
English	9d. to 10d.	20d.	24d.
Australian	4½d. to 5d.	11d. to 13d.	6d. to 10d.

Comparable prices for other offals are not available, but the discrepancy between them is usually quite as large.

While a complete survey of this branch of the trade has not been made, the chief defects of the Australian material would appear to be:—

(*a*) A "slushy" texture of the flesh after thawing.

(*b*) The presence of extensive, superficial, whitish patches, which detract considerably from the appearance.

The cause of the former trouble is not definitely known, but it is likely that the rate of freezing is not sufficiently high to prevent serious alteration of texture.

The latter defect can probably be further subdivided into (i) "freezer-burn," and (ii) "storage-burn." The cause of "freezer-burn" lies probably in the strains set up during freezing causing distortion of the superficial cells, and hence light is reflected from shallower layers and is scattered by the heterogeneous arrangement of reflecting surfaces. The colour of the organ in such situations appears, therefore, to be considerably paler, although no change may have taken place in the actual concentration of the pigment. "Storage burn" appears to be due chiefly to desiccation. While careful attention to handling and wrapping has reduced the losses by both "freezer" and "storage" burns, their occurrence is still far too frequent.

It is recommended, therefore, that the Council undertakes an investigation designed to freeze, store, and transport frozen edible offals in such a way that, on thawing, they do not differ materially from similar fresh produce.

An inquiry in the principal abattoirs devoted both to the local and export trade showed that very little use was being made of various animal organs and ductless glands for the purposes of pharmaceutical preparations. As the separation of these organs and glands would probably be profitable only in meat works where a very large number of animals are slaughtered each year, the considerable neglect in such establishments in Melbourne and Sydney of these preparations, undoubtedly a very profitable source of income for the American meat packers, indicates a direction for future developments.

While the Council is at present not in a position to undertake an investigation designed to obtain the best methods of utilization, the position should be borne in mind and possibly investigations be undertaken at a later stage.

(v) *General Meat Works Technique.*

One of the most outstanding of the general problems confronting all cold storage plants is the prevention of desiccation of the stored foodstuffs, and, with regard to stored meat, the effects, not only of total loss of moisture, but also of superficial desiccation on the appearance, are perhaps more serious than in any other foodstuff. As this problem is, however, essentially physical in nature, further reference to it will be made in the section dealing with engineering problems.

Although the general methods of treatment of carcasses and edible offal throughout the meat works in Australia appear to be yielding fairly satisfactory results, except as indicated above, one cannot but be struck with the lack of exact knowledge on minor points and the conflicting reasons given by works managers for the methods used. For instance, in order to utilize as small an amount of freezing space as possible for a given amount of meat to be frozen, certain works make a practice of freezing quarters of beef as rapidly as possible, frequently in rather less than four days. In other works, with ample freezing space, relatively rapid freezing is practised because the management believe that the texture and flavour of the meat is superior to the more slowly frozen meat after thawing, and several influential men in the trade, if given the opportunity, would make such relatively rapid freezing compulsory. In many freezing works, a period of six to seven days is allowed for the freezing of beef. There is no scientific evidence to show that, in general, the slower freezing produces a poorer texture and flavour in beef than does freezing rather more rapidly (excluding, of course, freezing times of the order of several hours).

For the storage of frozen meat, many works maintain temperatures in the bulk stores ranging from — 2° to 5° F. In several works situated at considerable distances from the ports of export, and where the insulated railway wagons are frequently defective, maintenance of this low temperature is essential in order that the meat may not soften *en route* to the overseas vessels. But in many works situated close to or alongside the wharfs these low temperatures are also maintained. The minimum temperature at which bacterial and fungal growth may occur is approximately 18° F., and the temperature above which distortion of the meat under pressure may occur is approximately 16° F. It is advisable, of course, to allow a fairly wide margin of safety in case of a breakdown of the refrigerating equipment, and, therefore, maintenance of a temperature in the stores ranging from 10° to 13° F. would appear to be advisable, but there exist no reasons, apart from those stated above, why meat frozen by present methods should be maintained at such a low temperature as 0° F., which, naturally, is expensive to reach and maintain, particularly during the summer months.

Many other general questions arise, but it will be sufficient only to mention one, viz., whether the subsequent texture and flavour of the frozen meat would be improved to any marked degree by allowing it to hang before freezing for longer periods than are at present employed. (After slaughter, the sides of beef are hung overnight in chilling rooms kept at 30° F. approximately, and lambs' and sheep's carcasses are hung in unrefrigerated cooling floors for periods ranging from one to seven hours.) Any improvements so introduced would, of course, be offset by the extra cooling space required and the probable slightly higher losses of weight (moisture) taking place from the meat.

(vi) *Rabbits.*

In Victoria, the institution of excellent methods for the rapid collection, chilling, and despatch of rabbits from the country districts to the packing and freezing works in Melbourne have resulted in elimination of most of the losses previously experienced due to the onset of yellowing of the fat and bacterial taint of the flesh. On arrival in England, considerable deterioration in rabbits from New South Wales is frequently found—chiefly the presence of strong odours, probably bacterial in origin, and extensive yellowness of the superficial fatty tissues. It is probable that the general mode of treatment in New South Wales prior to packing for export is largely responsible for this unsatisfactory state of affairs. In the rural districts, the bulk of the rabbits are usually packed loosely in boxes, and chilled or partially frozen. They are then despatched to the packing and freezing works in Sydney, and here they are thawed, graded, packed into crates, and frozen. The delay, both during collection and during the time occupied by thawing, probably accounts for the bulk of the troubles experienced. In addition, considerable losses are experienced annually by the formation of superficial "corkiness" (desiccation) in the flesh.

Most of the difficulties requiring remedies have been dealt with in the investigation carried out at the Low Temperature Station, Cambridge, and it is felt that the results of this investigation provide sufficient data to secure the elimination of most of the defects experienced. The defect of superficial desiccation belongs rather to the general problem of desiccation of foodstuffs in cold storage, and it is expected that any general physical data obtained in regard to that problem would be applicable also to the prevention of desiccation during the freezing and storage of rabbits.

(vii) *Canned Meat.*

In general, the canners experience few troubles in canning either mutton, beef, or rabbits; close attention to cleanliness and efficient methods of sterilization have eliminated most of the subsequent tainting and "blowing" of the cans formerly experienced. The chief source of loss, though one not frequently met with, is the development of the so-called "black spot" on the meat.

For some years past there has been very little demand, however, for canned meats, and it is difficult even to sell the highest quality "packs." In the circumstances, therefore, it is considered unnecessary for the Council to undertake any critical scientific studies of the canning of meat.

3. Fish.*

The investigations carried out by the Federal investigation trawler *Endeavour,* and the comprehensive inquiries undertaken by the Development and Migration Commission in conjunction with the States, established the existence of fairly considerable resources of demersal (bottom-feeding) fish off the coasts of Australia. With the exception of the inshore fish, little exact knowledge of the resources of pelagic (surface) fish is available. Until one or two experimental fishing vessels working in conjunction with a marine biological laboratory are employed in a systematic study of our waters, not even an approximate idea of the potential resources or the most profitable methods of catching and distribution of the fish can be obtained.

Extensive grounds, where the existence of considerable quantities of pelagic fish have been observed, occur off the southern and eastern coasts of Tasmania, but, except for a small quantity of fresh and cured (smoked) fish (barracouta) sent to the mainland, the production is limited to supplying the small local demand for fresh fish. Other pelagic fishes, such as the pilchard, are not yet commercially exploited. That greatly increased quantities of fish could be caught by the Tasmanian fishermen is apparent from the fact that the time spent in port while the catches are being sold in a live state bears a high ratio to the time occupied by the fishing operations.

The capital cities of Australia, with the exception, possibly, of Sydney, do not receive regular supplies of fish at a price which the majority of the citizens can afford, and their *per capita* consumption of fresh fish is low compared with British cities. In the country districts, particularly during the summer months, only meagre supplies of fish are available, and resort is, therefore, made to the imported canned products. There would appear, therefore, to be distinct possibilities for a development of a more extensive fish trade between Tasmania and the mainland, provided that difficulties of transport could be overcome, probably by means of quick freezing. Of the numerous types of popular fish—at present being commercially captured—existing off the coasts of Tasmania, the barracouta, black perch, and cod are probably the most common. Of these, the barracouta lends itself particularly well to the production of fillets, which could be packaged and frozen in the manner so extensively practised in the United States of America. If sufficient capital were available to rationalize the Tasmanian fishing industry, by freezing both whole fish and fillets, by curing a portion of the catch, and by manufacturing fish meal from the waste portions of the filleted fish and the numerous types of less popular fish caught off these coasts, Tamania would be in a position to contribute substantially to Australia's supply of foodstuffs. An obstacle to such a development at present is the lack of adequate shipping facilities from Hobart, which would, most probably, be the centre of such large-scale treatment works. The vessels plying between the mainland and Tasmania at present have no refrigerated space in the cargo holds, but this difficulty is not insuperable.

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* In preparing this section, valuable assistance has been given by Mr. S. Fowler, of the Development Branch of the Prime Minister's Department.

† On behalf of the Australian Fisheries Conference.

Large quantities of sardine-like fish are said to exist in the warm current that sweeps the north-east corner of Tasmania. It may be possible, therefore, to establish nearby, a canning industry linked with a plant for the production of fish meal. During the year 1929-30, Australia imported 29,000,000 lb. (approximately) of dried, smoked, and canned fish, in addition to 7,500,000 lb. of fresh and frozen fish, the bulk of which, with the exception of canned salmon, could be replaced by the Australian product.

The greater proportion of the sea fish caught by New South Wales fishermen is forwarded to Sydney. Of these supplies, slightly less than one-half is estuarine fish caught by hand line and net, while the remainder consists of fish supplied by sixteen privately-owned trawlers, whose base of operations is Sydney.* Owing to its greater specialization and concentration of supplies on one port, it is to the trawling industry that New South Wales must largely look for improved methods of treatment and distribution. The trawlers now operate on fishing grounds extending from Port Stephens to Flinders Island, in the east of Bass Strait, aiming to catch chiefly flathead. All other fish, with the exception of some leatherjacket, gurnard, and perch (from southern waters), amounting frequently to one-half of the total catch, are returned to the sea. With a more highly capitalized industry, the owners of the trawlers believe it would be possible to institute a wider system of distribution by quick-freezing part of the catch, and to retain all edible fish caught, using the less popular varieties for the production of fish meal. It is understood that within the last few years the average weights of the hauls of flathead from the fishing grounds nearer Sydney have diminished very considerably. Opinion seems divided as to the causes of this falling-off. With the present meagre data it is impossible accurately to establish the real cause; it is possible that the present scarcity may be due to some unknown biological factor. Such periods of scarcity are common overseas.

Practically, no use is being made of non-estuarine surface fish, large shoals of which, particularly the herring family, are said to exist off the coast of New South Wales. Until catches of these fish with equipment such as, say, drift nets or purse seines, are made and proved to be feasible commercially, little can be said concerning a phase of the industry which would probably lend itself readily to an organization similar to that suggested for the trawling section.

There is very limited information concerning the extent of the resources of pelagic fish off the coasts of Victoria, South Australia, and Queensland, and it seems probable that the resources of demersal fish close to the large centres of consumption in these three States are probably very limited in extent and abundance, and, at present, can scarcely be considered in any rational scheme of re-organization of the industry. Extensive fishing grounds exist in the Western Australian section of the Great Australian Bight and off the north-west coast of Western Australia, but until a considerably larger local population exists, economic difficulties may prevent their extensive exploitation, at least in the form of fresh fish.

Athough, at present, it appears inopportune for the Council to attack the scientific problems concerned in the preservation, storage, and transport of fish in Australia, the extensive possibilities of develop-

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* During the year 1929 the trawlers supplied approximately 12,000,000 lb. of fish to the Sydney Municipal Market.

ment warrant the position being closely watched, so that experiments can be initiated to establish the required data on problems of distribution when schemes for the large-scale development of our fisheries are being put into operation.

4. Dairy Produce.

(i) *Butter.*

Discussions with various officers of the Dairy Products Export Branch of the Commonwealth Department of Markets and the Dairy Experts of the several State Departments of Agriculture, and visits to butter factories in Tasmania, Victoria, and Queensland, showed that the chief cause of deterioration of texture and flavour of butter in cold storage is bacterial contamination during the operations on the farms, and, to a lesser extent, in the dairy factories. In this connexion the experience of the industry in New South Wales only need be mentioned. Prior to the year 1915, no effective legislation existed giving power to the dairy inspectors to compel the farmers and owners of the dairy factories to introduce methods and equipment which careful investigation had shown to be effective in producing butters free from taints and capable of being held in cold storage for long periods. In the year 1915, approximately 30 per cent. of the butter manufactured in New South Wales was graded as choice (top grade). As a result, both of wise legislation and the complementary educational campaign to introduce greater cleanliness into the industry, more than 90 per cent. of the butter produced in New South Wales is now graded as choice.

It is the opinion of all disinterested men in the dairy industry that, provided butter be manufactured from choice creams, the present methods of its handling and cold storage are wholly satisfactory to maintain the original (Australian) grading on the overseas market.

The inquiry into the causes of butters being tainted on arrival on the overseas markets (with the exception of taints acquired from their surroundings during storage) is reduced chiefly to a consideration of the frequent occurrence, particularly in Victoria and Tasmania, of low-grade creams delivered to the dairy factories. While the defects appear to be due chiefly to bacterial contamination, intensified by excessive temperatures of the creams during the period elapsing between milking and arrival at the factory and by delayed delivery, some creams appear to be more susceptible to bacterial decomposition than others. It is possible that these changes are closely related to the chemical composition of the creams, which, in turn, is dependent partly on the breed of the cow and partly on the nature of its diet. While, however, these defects require somewhat extensive scientific investigation before they can be overcome, a considerable improvement of the quality of Australian butters could be attained by a stricter regard for cleanliness.

(ii) *Cheese.*

Queensland is practically the only State from which cheese is exported, but, on the whole, the quality is not high grade.

In general, no peculiar difficulties are experienced during the cold storage of this product. Since cold storage is utilized not only to preserve the cheese but also to effect its gradual maturation, a definite relationship obviously exists between the temperature of storage and the rate and nature of maturation. As little information on this subject is available, it merits close study, since, in order to establish a steady market overseas, it is essential to place the cheeses on the market in a uniform degree of maturity.

In the manufacture of cheese during the early summer months, difficulties are frequently encountered in securing a good "body," i.e., at the completion of the milling operations, the cheese, instead of being "rubbery," has an open granular texture, and, therefore, disintegrates too easily.

(iii) *Eggs.*

The export of chilled eggs—carried at a temperature of 32° to 34° F.—has assumed fairly considerable proportions in Australia during the last few years, the average annual quantity exported during the last five years being 2,445,000 dozen.

The experience recently gained by the trade and ships' engineers has eliminated most of the losses due to fungal attack, but considerable depreciation in the quality of the eggs is often caused by relatively excessive evaporation of their moisture content. This defect occurs particularly in ships' holds refrigerated by the dry-battery air-circulation system, which otherwise very successfully inhibits fungal attack.

(iv) *Recommendations.*

The problems relating to the storage and transport of butter and cheese are intimately related to the conditions existing on the farms and in the dairy factories, and are, in general, localized in occurrence. They require for their solution the close co-operation of the well-organized dairy instruction and inspection staffs of the State Departments of Agriculture.

The problems general to all States relating to the treatment of the creams, the manufacture and transport of butter, and the manufacture and maturation of cheese, could probably be best attacked by research chemists and bacteriologists attached to the proposed Federal Dairy Research Laboratory, and working in close co-operation with the State Department of Agriculture. Problems more localized in nature could probably be best investigated by the Departments of Agriculture concerned.

It appears probable that the conditions most suited to the overseas transport of chilled eggs have still to be determined, and, while no definite recommendation for extensive investigations in this field can be made, a preliminary inquiry should be carried out by the Council's engineer-physicist as part of his general survey of the transport of chilled and frozen foodstuffs from Australia.

5. Fruit.

General.

Apples and pears form the bulk of the exports of fresh fruits from Australia, relatively small quantities of oranges, grapes, and plums forming the remainder. The bulk of the export trade is directed toward Great Britain, but Germany and Canada are beginning to absorb increasing quantities. Except for the relatively small quantity exported to New Zealand, India, and Java, the fruit is transported overseas in ships' insulated holds cooled to temperatures varying from 30° to 45° F.

With the exception of pears exported from Victoria, the greater part of the fruit is not pre-cooled to the approximate temperature of transport prior to shipment.

The wastage of fresh fruit exported from the Dominions in the Southern Hemisphere has often seriously imperilled the economic stability of the sections of the community dependent on this trade. Many scientific investigations, therefore, have been initiated to study the nature, causes, and methods of elimination of the wastage.

As is the case with all primary produce grown in Australia, with the exception of wool and wheat, the home market provides a larger outlet for fresh fruit than do the overseas markets. In addition to a large intra-state distribution of fruit frequently stabilized by cold storage of portion of the crop, a considerable interstate movement of fruit now occurs. In the latter trade, the transportation of apples and pears from Victoria and Tasmania to New South Wales and Queensland, and of tropical fruits from Queensland to all the other States are the most important sections.

Fruit being a living, and, therefore, respiring material, its death after picking normally takes place when a certain fraction of the available sources of energy (chiefly carbohydrates) is exhausted; the rate of consumption of these reserve supplies is greater the higher the temperature. It would appear, therefore, that death of the fruit would occur more rapidly during storage at higher than at lower temperatures. This statement, however, is only approximately correct on account of the fact that for different kinds of fruit, and for different varieties within each kind, there exist certain critical, environmental temperatures below which the metabolism of the fruit is disorganized, leading to onset of one of the many so-called physiological disorders; progressive onset of death in the affected cells of each fruit will then take place. The duration of the "life" of the fruits after picking, therefore, is dependent upon the temperature—time relationships occurring in each subsequent stage. Other environmental factors influencing the post-picking life of the fruit are the composition of the surrounding atmosphere, and, probably, the degree of saturation of the air with aqueous vapour.

The pre-picking factors influencing the subsequent storage life have not been fully defined, but certainly include the type of root-stock, the type of soil (including the type of manuring), the climatic conditions, the cultural treatment, the degree of infestation of the plants by insects and fungi, the size of the crop, and the degree of maturity at picking.

For fruit exported from Australia there are, therefore, numerous closely inter-related pre-shipment, transportation, and post-shipment factors which determine the average "life" of the material; only by a careful study of each factor and its inter-relationships with other factors can any light be thrown upon the causes and methods of elimination of the wastage.

During the last few years, extensive investigations, particularly in England and the United States of America, have defined and analyzed many of the factors stated above, particularly for the apple; but, apart from the work of Carne in Western Australia, the Citrus Preservation Committee of the Council, and the Victorian Departments of Agriculture and of Railways, little systematic study of these factors or the application of the findings of overseas investigators has been undertaken in Australia. While it is probable that the results of many investigations conducted outside Australia can be applied here without considerable modification, accurate information is particularly required in each exporting State concerning the susceptibility of certain varieties of each kind of fruit to physiological disease and fungal attack; in other words, definitions of their "biological characteristics" are required.

The economic aspects and the chief problems of the export trade in each kind of fruit will now be outlined. It will be convenient, however, to consider apples and pears together.

(i) *Apples and Pears.*

The average annual production of apples in Australia during the last five years has been of the order of 7½ million bushels, of which approximately 2,600,000 bushels were exported (see Table I.).

TABLE I.—AVERAGE PRODUCTION AND EXPORT OF APPLES.

State.	Average Annual Production Apples.	Average Annual Export.
	Thousand Bushels.	Thousand Bushels
Tasmania	3,283	1,629
Western Australia ..	723	393
Victoria	1,836	372
South Australia ..	728	175
New South Wales ..	780	27
Queensland	180*	3*
Total ..	7,530	2,599

* Approximately.

The corresponding figures for pears (1926-29) are—

TABLE II.—AVERAGE PRODUCTION AND EXPORT OF PEARS.

State.	Average Annual Production.	Average Annual Export Fresh Fruit.
	Bushels.	Bushels.
Tasmania	184,500	74,787
Victoria	792,951	59,888
Western Australia ..	92,189	24,721
New South Wales ..	252,975	6,313
South Australia ..	168,701	3,462
Queensland	10,781	26
Total ..	1,502,097	169,197

With the recent increased production of apples and pears there seems to have been increased export, particularly as regards apples from Tasmania and Western Australia, and pears from Victoria.

The tables show that Tasmania, Victoria, and Western Australia are the chief exporting States. Since alternate light and heavy cropping appears to be characteristic of the production of both apples and pears, the average values given above do not truly indicate the extent of production, and, therefore, the surplus available for export in any given year. For instance, during the year 1927-28, 11,500,000 bushels of apples were produced in Australia, of which approximately 4,300,000 bushels were exported, whereas in the following year, 1928-29, the total production was only 5,500,000 bushels, which allowed an export of only 1,600,000 bushels (approximately).

The chief varieties of apples and pears exported may be tabulated as follows:—

TABLE III.—CHIEF VARIETIES OF APPLES AND PEARS.

Apples.				Pears.	
Tasmania.	Victoria.	Western Australia.	New South Wales.	Victoria.	Tasmania.
Sturmer Jonathan Cox's Orange Pippin Cleopatra	Jonathan Five Crown Rome Beauty Yates' Seedling	Jonathan Cleopatra Dunn's Granny Smith	Granny Smith Jonathan	Packham's Triumph Beurre Bosc Josephine Keiffer	Beurre Bosc Josephine Keiffer

Export of the early maturing varieties of pears commences from Victoria early in February, and later in the same month is generally followed with the initial shipment of early maturing varieties of apples from Victoria and Western Australia. Regular shipments then continue to take place every few days until the middle of June, when the final cargoes of Tasmanian apples are loaded. Between 40 per cent. and 50 per cent. of the apples and pears exported from Australia are discharged at London, about 20 per cent. at Hamburg, and the remainder chiefly at numerous United Kingdom ports, such as Liverpool, Hull, and Glasgow.

The conditions existing in ships' holds during transport overseas will be considered more fully in the section devoted to transport and engineering problems, but it is useful here to draw attention to several outstanding features. Owing chiefly to lack of collective organization in the States exporting large quantities of apples and pears, and lack of co-ordination between the various States, holds are frequently not completely filled at one port, and loading is completed at later ports of call.

The temperature which the ships' engineers aim to maintain in the holds carrying apples ranges from 33° to 36° F., while the holds containing pears are usually kept at temperatures varying from 29° to 34° F. The time during which the fruit may remain in the holds varies from 30 to 56 days.

After discharge at the British ports, the fruit is forwarded to the agents for sale, either at the warehouses of firms selling by private treaty or to agents who operate at the auction markets. In both of these methods of distribution the fruit is sold to wholesale dealers, who, in turn, distribute it to the retailers. Even with the aid, or perhaps on account, of the complex organization apparently necessary for the distribution of large quantities of fruit arriving on the English markets during the months of April, May, and June, the period elapsing between the discharge of the fruit at the docks and its delivery to the retailer is as great as two to five weeks.

Judgment of the effectiveness of the present technique employed in the export of apples and pears can, of course, only be made by a consideration of the condition in which the fruit is placed in the hands of the retailers overseas. While investigations carried out in England have approximately defined the chief types of wastage present in shipments of Australian apples and pears (British Food Investigation Board, Special Report, No. 38), no complete surveys have been made to determine the average per centum wastage occurring up to the time of disposal of the fruit to the retailers.

An approximate conception of the extent of the wastage may be obtained by tabulating the reports of the various State Agents-General upon the condition of Australian shipments of apples and pears on arrival in England during the years 1927 to 1930. The reports, however, are incomplete, as numerous shipments each year are not commented upon, and no data are given concerning the nature of the wastage.

TABLE IV.—CONDITION OF FRUIT CARGOES FOR YEARS 1927 TO 1930.

Year.	Condition of Cargoes.			Type of Refrigeration on Boats.	
	Description.	Number of Each.	Percentage of Total.	Number Having Brine Grids.	Number Having Dry-battery.
1927.			%		
Small quantity exported	Excellent	1	3	1	..
	Good	34	87	14	20
	Wholly or partly unsatisfactory	4	10	..	4
1928.					
Large quantity exported	Excellent	1	2	..	..
	Good	7	14	2	7
	Wholly or partly unsatisfactory	44	84	20	24
1929.					
Small quantity exported	Excellent	1	4	..	1
	Good	18	62	6	12
	Wholly or partly unsatisfactory	10	34	4	6
1930.					
Large quantity exported	Excellent	1	2	1	..
	Good	18	35	4	14
	Wholly or partly unsatisfactory	32	63	22	10

This table shows that the condition in which the fruit arrives in Great Britain, in general, is unsatisfactory, particularly in the years of greatest export; the cargoes showing wastage constituted 84 per cent. and 63 per cent. of the total examined during the years quoted.

The report on the fruit investigation during the Australian and New Zealand season 1927, issued by the Empire Marketing Board (Special Report, No. 3) defines fairly accurately the extent of the wastage occurring up to the time of discharge of the fruit at the English docks, but these results must be considered in conjunction with the incomplete figures given by Barker (British Food Investigation Board, Special Report, No. 38) for the development of further wastage during marketing.

The Marketing Board survey showed that in 1927—a year of small exports—the following wastage occurred in different varieties of Tasmanian and Western Australian apples:—

TABLE V.—WASTAGE IN WESTERN AUSTRALIAN AND TASMANIAN APPLES DURING YEAR 1927.

Variety.	Bitter Pit		Internal Breakdown		Fungal Rotting (following bruising)	
	Tasmania.	Western Australia.	Tasmania.	Western Australia.	Tasmania.	Western Australia.
	%	%	%	%	%	%
Cox's Orange Pippin ..	21	..	4	..	2·1	..
Cleopatra	10	18	·2?	<1?	·8	·5
Sturmer Pippin ..	9	<1	·1	..	·4	·3
Ribston Pippin ..	9	..	3·0	..	·8	..
Jonathan	1?	4?	3·0	5	·4	·7
Dunn's Seedling ..	7	1	2·0	..	·9	·7
Alfriston	2	..	2·0	..	·5	..
Scarlet Pearmain ..	1	..	·3	..	1·5	..
Rome Beauty ..	..	2	..	<1	..	1·0
Granny Smith ..	..	7	..	..	..	..

Barker's survey has rather clearly shown that over-ripeness, bruising, fungal rotting, bitter pit, and internal breakdown cause the bulk of the losses in Australian fruit. Barker has shown, too, that wastage, particularly that due to internal breakdown, may increase very rapidly after discharge of the fruit from the overseas boats, during which time it is subject to ordinary atmospheric temperatures (English summer). For instance, the incidence of internal breakdown of Victorian Jonathan apples rose from 0 to 22 per cent. during a period of 21 days after discharge, and from 0.7 per cent. to 25.8 per cent. in Tasmanian Cox's Orange Pippin apples during the period from the fifth to the eighteenth day after discharge. The incidence of fungal rotting, too, in Victorian Jonathan apples increased from 5.5 to 19.5 per cent. between the third and twenty-fourth day after discharge. It is probable, therefore, that the extent of the wastage given in Table V., at least that due to internal breakdown and fungal rotting (associated so frequently with over-ripeness), may be doubled after the normal period of holding during marketing—two to three weeks—has elapsed. While considerable wastage usually occurs in the early shipments due to the presence of bitter pit, the later shipments, particularly those arriving in England during June, seem to show the greatest incidence of wastage due chiefly to the presence of over-ripeness and the concomitant fungal rotting.

Very few data exist concerning the type and distribution of wastage in Australian pears. Over-ripeness or "sleepiness," however, appears to be the chief cause of wastage, while core-breakdown, scald, bruising, and abnormal ripening (death of the fruit may result while it is still green, juiceless, and tough) contribute materially to the losses sustained.

The possible causes of this extensive wastage in Australian apples and pears have been fully considered by Barker (*loc. cit.*); in the light of experience gained during a recent survey of the export of apples and pears from Victoria and Tasmania, further comment will be made on possible causes and the experimental investigations needed to confirm them.

It has been repeatedly alleged, and, I believe, on fairly substantial grounds, that exported apples and pears frequently arrive on foreign markets in a wasty condition, while exactly similar fruit placed in cold storage at the time of shipment of the exported fruit retains a firm, healthy condition for several months after the time of discharge of the exported portion. While this apparent discrepancy in storage life may, perhaps, be partially accounted for by more prompt cooling and by the possibility of less mechanical damage of the land-stored fruit, it is probably due, in general, to the unsatisfactory conditions of cooling and ventilation in the ships' holds, and particularly the deep lower holds. Investigations of physical conditions existing in ships' holds and the consequent condition of the fruit stored in them have been carried out by Smith (British Food Investigation Board, Special Report, No. 27), Barker (British Food Investigation Board, Special Report, No. 39), and E. A. Griffiths and R. Davies (Union of South Africa Department of Agriculture, Science Bulletin, No. 56), and have demonstrated effectively that the rates of cooling of cargoes of fruit are usually slow, that wide variations of temperature exist both in space and time, and that wastage is usually greatest at positions where the rate of cooling is slowest. The problem of securing uniform physical conditions in ships' holds carrying fruit is the most urgent need of the technical side of the industry, and it is probable that its satisfactory solution will result in markedly lower wastage in Australian cargoes.

This problem, however, is closely bound up with the vexed question of cooling the fruit prior to shipment. The ships' engineers are, at present, faced with the almost impossible task of attempting rapidly to cool a closely stacked hold of hot fruit. Attempts to cool it too rapidly are liable to cause freezing of the fruit close to the position of application of the "cold." The apparent success of the South African arrangements for the pre-cooling of all fruit exported from the Union, and the reduction of the wastage of pears following their compulsory pre-cooling prior to export from Victoria, show the extreme desirability of this technique. Pre-cooling, however, has the added advantage of minimizing the effects of delays between the time of picking and shipment. During the "peak" of the season (March and April), when the fruit must be picked, packed, and exported as rapidly as possible, large accumulations of apples tend to occur in the packing sheds and on the Tasmanian wharfs, where they are exposed frequently to high temperatures for periods up to ten days in duration. Pre-cooling of all fruit exported from Australia will probably become general in the near future, but such a desirable change will result, not so much from the weight of scientific evidence, as from the fact that exporters will otherwise find it more and more difficult to pick, pack, and ship the chief early and mid-season varieties of apples in the short space of time in which they reach the optimum maturity in any one district. For instance, in the Mornington Peninsula District of Victoria, the total period during which the bulk of the Jonathan apple crop is at the optimum maturity is only of about ten days' duration. Even at present, considerable congestion occurs in the packing sheds during this period, and, owing to the impossibility of securing adequate shipping space, the fruit tends to lie in the packing sheds for periods up to two weeks in duration, and, therefore, to become too mature for safe transport.

Other factors within the control of the industry and influencing the onset of wastage and diminished storage life are extremely numerous, and may be traced as far back as the orchard. To a limited extent, the type of soil may influence the subsequent storage life, and investigations may show the desirability of eliminating from export the fruit from orchards situated on soils unsuited to the growing of certain varieties. The type of root-stock may also be important. At present it seems certain that the seedling apple stock used exclusively in Southern Tasmania gives rise to heavier yields than does the Northern Spy stock used almost exclusively on the mainland, but, as yet, very little is known concerning the relationship between the type of root-stock and subsequent keeping qualities of the fruit. The varieties within each kind of fruit grown, too, may need considerable modification if the export industry is to be placed on a rational basis. Force of economic circumstances is gradually eliminating certain varieties of apples undesirable from the point of view of export, e.g., Ribston Pippin, and encouraging others, such as Granny Smith, which appear to have desirable characteristics. Apart altogether from the undesirability of exporting too many varieties of apples, investigations are needed to give a basis for an accelerated rate of elimination. Plant-breeding experiments, too, are needed to produce new varieties which will yield not only good regular crops, relatively free from disease, but which will also yield fruit possessing good flavour and colour, and, perhaps, more important still, having a long storage life.

Variations of cultural practice, including manuring, will undoubtedly influence the chemical composition of the fruit, and hence its storage life, which is probably controlled, in part at least, by the relative concentrations of carbohydrates, nitrogenous bodies, and the various mineral constituents.

Orchard sanitation, which fortunately is now being closely attended to and which probably influences the rate of onset of some forms of fungal attack of the fruit, and the degree of maturity at picking, are other factors within the easy control of the orchardist.

It seems probable that considerable wastage by fungal attack is caused by the bruising of the fruit inevitably following defective packing and rough handling of the cases. Although numerous improvements in these matters have been introduced during the last few years, inspection of many cases of apples and pears on the wharves prior to shipment showed that bruised fruits were frequently present, particularly in positions close to the bulged sides of the cases. The ideal case for export has still to be evolved.

The relatively long period elapsing between the time of discharge of the fruit at overseas ports and its sale to the retailers must undoubtedly lead to severe wastage in material, which has probably already suffered from the effects of delays in Australia. Accelerated disposal of the fruit is essential, or if that be impossible, cold storage of the more delicate varieties pending sale.

It is apparent that a considerable body of empirical knowledge, but little exact evidence, exists as to the causes and methods of prevention of the various types of wastage of Australian apples and pears. Research work already carried out in Australia has at least partially defined the nature of the waste likely to occur and, in some cases, has suggested possible methods of control. The work of Carne and his associates in Western Australia has shown that the type of bitter pit occurring in Cleopatra apples during cold storage can largely be controlled by avoiding premature picking. The effect of the temperature of storage in controlling the development of pit has not been fully established. Work by Thomas in Tasmania and Tindale in Victoria has shown that climatic and tree factors appear to modify the incidence of pit and its relationship to the optimum degree of maturity desirable at picking. Further work on bitter pit in Victoria and Tasmania, and particularly on varieties other than Cleopatra, appears to be needed, chiefly on account of the fact that the work of Adam in Victoria (1923) on the development of Jonathan spot and that of Thomas on internal breakdown has shown that the rates of onset of these "diseases" are accelerated by later picking. For early and mid-season varieties of the "delicate" cold storage type, e.g., Cox's Orange Pippin, Jonathan, and Ribston Pippin, the orchardist appears to be between the Scylla of bitter pit and the Charybdis of internal breakdown. The work of Adam (1923) and Adam and Harrison (1925) in Victoria, and of Broadfoot in New South Wales, concerning the development of scald in apples, particularly in the popular variety "Granny Smith," has shown that it may be partially controlled by storage at low temperature (32° F.), by adequate ventilation, and, more especially, by wrapping the fruit in oiled paper.

Investigations on the storage of pears are not so complete, but the investigations of Adam and Tindale in Victoria have, at least, stressed the fact that their storage life is much shorter than that of most apples. They have shown, too, the importance of storage at as low a temperature as possible—from 29° to 31° F.—in order to reduce the rate of onset of ripening and reduce the onset of superficial blackening in certain varieties, e.g., Keiffer. Adam and Harrison have found that later picking of Williams Bon Chrétien pears is conducive to normal ripening after removal from cold storage.

A large number of vital investigations, therefore, need to be undertaken; those most urgently required fall into three categories:—

(*a*) Biochemical investigation of the relationship between the concentrations of the various organic and inorganic constituents of the fruit and the storage life. Without these data most attempts to extend the storage life by alterations in the pre-storage factors must be largely empirical.

(*b*) The influence of the various controllable pre-storage factors such as the type of root-stock, the cultural practice—including manuring—the orchard sanitation, and the degree of maturity at picking upon the storage life under different environmental conditions of storage.

(*c*) The direct relationship between the physical conditions existing in the storage environment, e.g., temperature, relative humidity, and the composition of the atmosphere, and the storage life of the fruit.

The specific investigations in each category which need to be attacked initially are—

(*a*) The biochemical studies, necessarily tedious and probably extending over many years, may perhaps be commenced with a study of the relationships between the concentrations of organic and inorganic phosphates and the carbohydrate constituents, and the inter-relationships between these factors and the storage life of both pears and apples.

(*b*) In this field, the relationship between the maturity and the development of bitter pit and internal breakdown in apples needs to be further investigated for the chief varieties exported from Victoria and Tasmania. Studies of the relationship between the degree of maturity of pears at picking and the development of scald and of abnormal ripening need to be undertaken. The effect upon the storage life of apples of various artificial manures applied to the trees needs also to be investigated, since this method of control is relatively simple.

(*c*) In this category, investigations are urgently needed to elucidate the effects of temperature, percentage composition and relative humidity of the air in the storage environment on the development of the four chief causes of wastage in Australian apples, viz., over-ripeness, fungal attack, bitter pit, and internal breakdown. It is suggested that these experiments be conducted on the chief varieties exported from Tasmania and Victoria, e.g., Tasmanian Sturmer Pippin, Cox's Orange Pippin, Cleopatra, and Jonathan, and Victorian Jonathan, Granny Smith, Rome Beauty, and Yates' Seedling varieties. These data are urgently needed to establish the correct temperature for the overseas transport of mixed cargoes in which these varieties will usually predominate, and also to provide data for the engineer-physicists who will be seeking to establish uniform physical conditions in ships' holds containing fruit. A critical study of the effects of different storage temperatures on the ripening of the chief varieties of Victorian and Tasmanian pears subsequent to removal from cold storage is also required. It may also be useful to explore the possibility of securing the safe transport of Williams Bon Chrétien pears, a variety perhaps distinctly superior to the chief varieties now exported, but which, it has been alleged, has poor keeping qualities.

(ii) *Citrus Fruits.*

Owing to the successful advertising campaigns directed towards securing greater consumption of citrus fruit in Australia and the uncertainty regarding the possibilities of successful transport, the amounts of citrus fruit exported from Australia have been relatively small, the bulk being shipped as ordinary cargo to New Zealand.

The following table gives the production of oranges in Australia during the year 1928-29; the bulk are of the Navel and Valencia types, each constituting approximately one-third of the total production.

TABLE VI.—SHOWING THE AUSTRALIAN PRODUCTION OF ORANGES (AND MANDARINS) DURING 1928-29.

State.	Production (bushels).
New South Wales	2,620,424
Victoria	378,101
Queensland	377,177
South Australia	362,527
Western Australia	243,054
Total	3,981,283

There are distinct indications that the limits of home consumption of oranges have been reached, and that, with ever-increasing production,* large quantities of the fruit must, in the future, be exported. It has been estimated, for instance, that by the end of the year 1935 there will be an exportable surplus amounting to 1,000,000 bushels (approximately). There appears to be no immediate prospect of an export trade in lemons and grape fruit.

It appears to be an urgent matter, therefore, that investigations be carried out in order to explore all methods likely to make possible the satisfactory transport of oranges to all parts of the world.

The investigations conducted by the Citrus Preservation Committee of the Council have enabled certain very important conclusions to be reached. It appears probable that, as the result of the method of dipping "sweated" oranges in warm solutions of sodium bicarbonate and spraying with paraffin, attack by moulds may be greatly arrested. Experiments, too, have shown that, with this treatment combined with storage at a temperature of 38° F., Valencia oranges may be successfully kept for periods up to four months in duration. Since the Valencia oranges are likely to reach the European markets approximately at the time of heavy supplies of Spanish and Palestinian oranges, the prospect of successful marketing does not appear bright. On the other hand, Navel oranges exported chiefly during June, July, and August will have to compete chiefly with those of South Africa and South America (Brazil). Unfortunately, the experiments of the above Committee have shown that the storage life of Navel oranges is rather limited; even with the bicarbonate treatment arresting fungal attack, the storage life is limited to a period of six to eight weeks, whereas, for successful export, the average storage life should be at least ten or twelve weeks. The conditions bringing about extensive wastage appear to be "flesh collapse" (probably a sign of senescence) and "skin collapse." While further studies on factors such as the "sweating" or "curing" of the fruit may bring about a partial extension of the storage life, it is unlikely that successful methods of control will be discovered until a thorough chemical investigation is undertaken with the view to the determination of the factors responsible for the differences in the rate of onset of senescence in Valencia and Navel oranges. It is hoped thereby that possible methods of control by variations of orchard practice may be suggested.

The feasibility of prolonging the storage life by means of gas storage—i.e., an increased proportion of carbon dioxide to oxygen in the environment—should also be considered.

(iii) *Grapes.*

It has been difficult to obtain figures relating to the amount of table grapes exported from Australia, but it is probably of the order of 1,000 tons, sent chiefly to New Zealand.

The studies of de Castella and Fish (Victoria) have shown the Ohanez variety to be superior in keeping qualities to all others grown in the southern States, and this variety now forms the bulk of the export. The grapes intended for export in cold storage are packed in a dry condition in flat, three-quarter bushel cases, the packing material being granulated cork. Fish showed that a combination of

* The figures for New South Wales alone for 1929–30 show that young trees not yet in bearing constitute one quarter of the total number. The proportion of young trees is probably considerably higher in the Murray Valley.

adequate orchard and packing shed sanitation, drying off of the surfaces of the berries prior to packing, and pre-cooling prior to shipment in holds maintained at a temperature of 33° to 34° F. would normally result in the grapes arriving at the most distant markets in a firm, saleable condition.

The chief causes of wastage in cold-stored grapes appear to be the detachment of the berries from the stalks and the onset of fungal rotting. With regard to these types of wastage, it may be of interest here to quote the conclusions arrived at by Barker (*loc. cit.*)—"Although the evidence suggests the desirability of earlier picking for the late consignments, and the importance of rapid transport at a low temperature, it must be realized that there is no evidence that dropping may not be due, in part at any rate, to too low a temperature of storage. What is needed is a comprehensive investigation of the relation between dropping and the condition of both culture and storage. . . . There is little doubt that rotting is related to the weakening of resistance to infection at the attachment of the stalk which accompanies the onset of over-ripeness."

It is probable, however, that the Ohanez is by no means the most attractive variety to export, and it appears desirable to carry out experiments designed to extend the range of varieties exported, particularly as the prospects of a profitable trade with Canada appear bright. A few experiments, with this object in view, have already been commenced in Queensland by Gregory, of the Department of Agriculture. He has found that it is possible to store the Purple Cornichon, Flame Tokay, and Red Malaga varieties at a temperature of 35° F. for a period of at least eight weeks, and the Black Muscat and Waltham Cross varieties for a period of about six weeks. Packing with wood wool and sulphite paper was found to be the most satisfactory for the former varieties and in granulated cork for the latter (softer) varieties.

Continuation of the Queensland experiments and further investigations of the causes of wastage, therefore, appear to be desirable, and could readily be carried out by the Council in conjunction with the Queensland Department of Agriculture which, I am assured, would co-operate closely in any investigation undertaken by the Council.*

(iv) *Plums.*

A small export trade in plums from Victoria has recently commenced. The work of Tindale, of the Victorian Department of Agriculture, has shown, in a preliminary way, the necessity for cooling before shipment, and has defined the optimum temperatures for their storage, viz., 30 to 32° F.

Further investigations would, I believe, be best carried out by the Victorian Department of Agriculture, although there appears to be some desire on the part of orchardists in the Stanthorpe district of Queensland for investigations to be carried out in Queensland to define the conditions necessary for successful transport overseas of plums grown in their district.

(v) *Peaches.*

As yet, no fresh peaches have been exported from Australia, and as Tindale (Victoria) has shown that the duration of the average

* The annual production of table grapes in Australia is 11,000 tons (approximately), and, in Queensland, 1,000 tons (approximately). The present production is thus by no means small and is sufficiently great to warrant investigations.

storage life of the usual table varieties is only about five weeks, it is unlikely that a profitable trade could be developed, except perhaps to the East and to Western Canada.

(vi) *Passion Fruit.*

Investigations on the storage of passion fruit have already been commenced in Victoria by the Council. It is hoped thereby to define the conditions necessary for the successful transport overseas of a fruit almost unique to Australia. The preliminary studies have yielded promising results, and have already suggested lines of future attack. As soon as the attractive qualities of this fruit are known overseas, it should form a profitable part of Australia's exports of primary produce.

(vii) *Bananas.*

Investigations on the maturation and transport of Queensland bananas were commenced some years ago by the Council, and are now nearing completion. They have defined the conditions to be adhered to in order that the fruit may be placed on the southern markets with a minimum of wastage and in a firm, ripe condition. In particular, the experiments have shown the efficacy of the method of ripening in the presence of low concentrations of ethylene. Several details, more particularly relating to the physical conditions of the storage environment to be maintained during transport, have still to be defined accurately.

(viii) *Pineapples.*

The Queensland Committee of Direction of Fruit Marketing has recently been requested by growers of pineapples to determine whether the export of pineapples overseas is feasible. Inquiries have shown that, during the months July to September, the approximate wholesale price per single fruit in England of South African pineapples varies from 4½d. to 7½d. according to the size and quality, while that of the best fruit from the Azores varies from 1s. to 3s. each. From details of costs supplied by the Committee of Direction, it appears probable that, in order to yield the Queensland growers a satisfactory return, the wholesale prices to be obtained in England should range from 8½d. to 1s. 4d. per single fruit according to size and quality. From personal observations made in England and Queensland, it appears that the quality of Queensland pineapples is superior to that of fruit grown in Natal, but it is difficult to state whether the Australian fruit would command prices substantially in advance of those received by South African growers.

The chief centres of production in Queensland lie in the metropolitan district and along the north coast line to Bundaberg. Excluding the sales of fresh fruit in Queensland, the production at present amounts approximately to 500,000 cases (of 1½ bushel capacity), of which 300,000 cases pass to the canning factories and 200,000 cases (approximately) to the southern States and New Zealand. The bulk of the fruit is produced during the periods February and March and June to October, and it is stated that the fruit ripening at the former period is much more susceptible to wastage during transport than that grown during the later period.

Apart from possible sources of wastage due to over-ripeness, the chief difficulties likely to be encountered in an export of pineapples are the presence of "water blister" and withering of the tops. The investigations carried out by the Council's Division of Plant Industry* have suggested methods of control for the former defect, but little knowledge is at present available concerning control of the latter.

Until a more remunerative market than exists in England be found, it is suggested that no investigations be undertaken by the Council.

5. Transport and Engineering Problems.

Reference has previously been made to the unsatisfactory conditions generally prevailing in ships' insulated holds carrying fruit from Australia to markets overseas, and the heavy wastage that frequently results therefrom. The problem of securing more uniform physical conditions in the storage environment is complicated by the fact that for every cargo of fruit in an insulated hold, at least two cargoes of frozen produce, such as meat and butter, are carried. The system of refrigeration employed, therefore, must be readily applicable to all types of foodstuffs transported in artificially cooled holds.

Realizing that the problem was so general and would probably require costly facilities for its solution, on a recent visit to England, the Chief Executive Officer of the Council (Dr. A. C. D. Rivett) formulated a plan of attack on this and related problems, whereby an investigation Empire-wide in its scope and personnel would be commenced. Although the idea apparently received wide acceptance, certain financial and administrative difficulties appeared to stand in the way of its fulfilment. The whole question still appears to be undecided, but, if the discussions now proceeding lead to approval of the scheme, the Council should attach to the team the engineer-physicist who is shortly joining the Council's research staff.

There appears to be no other adequate method of attacking what is perhaps the most urgent problem in the field of the export of Australian fruit and meat. In the event of the scheme for an Empire Refrigerated Transport Survey team not proving possible, it is suggested that negotiations be made with the British Food Investigation Board and the shipping companies for co-operation with their officers in a series of investigations of the performances of the more recent types of refrigeration employed in holds carrying fruit, and, perhaps, the application of data obtained at the Ditton (England) Experimental Ship's Hold. It is hoped that methods of obtaining more uniform physical conditions in the holds may, thereby, be discovered and applied.

In the interstate transport of foodstuffs, two problems are awaiting solution, viz., the elimination of wastage in the transport of tropical fruits from Queensland to the southern States, and of apples and pears from Tasmania to Queensland.

The tropical fruit at present is forwarded direct from Brisbane to Sydney and Melbourne in wooden, louvred, railway trucks, four train loads per week being sent. The fruit is stacked to give considerable free space around each box. During the autumn, winter, and spring, the fruit consigned to Victoria (transhipped at Albury) suffers relatively little wastage, except that the bananas are sometimes

* *Jour. Coun. Sci. Ind. Res., Aust.*, **4**: 152, 1931.

"chilled," and, subsequently fail to ripen normally. During the months December to March, serious losses of fruit consigned both to Sydney and Melbourne often occur.

Since a uniform railway gauge exists from Brisbane to Albury, the use of cooled insulated trucks on this route would probably solve the problem of summer wastage. Owing chiefly to the expense of re-icing the trucks and the lack of return freight, this method, however, seems difficult of application at the present time. An adequate survey of the problem, therefore, appears to be desirable, and could reasonably be undertaken by the engineer-physicist and a plant biochemist working in conjunction.

Apples and pears are forwarded in uninsulated ships' holds from Tasmania to New South Wales and Queensland. Early shipments consist chiefly of fruit sent direct from the orchards, but later shipments usually contain a considerable proportion of fruit which has been kept in cold store. While it is probable that a considerable proportion of the wastage is due to sending unsound fruit—types which would be rejected for export—and to the inevitable "sweating" of cold-stored fruit, it is possible that, particularly during March, April, and May, the transport facilities provided on the boats are inadequate. It is suggested that, perhaps, during the next fruit season, a survey be made by the engineer-physicist and a biochemist.

From time to time, the services of the engineer-physicist will be required to aid in the engineering problems arising out of the experiments on the chilling of beef. When the requisite physical conditions of the storage environment necessary for prolonged storage of the meat in the chilled condition have been formulated, it will be the task of the engineer to design refrigerating equipment to attain the specified conditions.

At the present time, the control over the rate of evaporation of moisture from foodstuffs in cold storage is more or less haphazard. In the discussion in the section devoted to meat problems, attention was drawn to the importance of the question, and it was suggested that the problems involved should be studied by the engineer-physicists attached to the Food Preservation Section. Beside the purely engineering problems involved, physical studies are required to discover the extent, rate, and mode of evaporation of moisture from various foodstuffs, particularly those stored in the frozen state, placed in atmospheres having different aqueous vapour pressures and different rates of movement. These studies will necessarily involve long-continued and difficult work, and, therefore, it is suggested that endeavours be made to have certain problems of a more academic, but nevertheless vital, nature studied in University laboratories by arrangement with the heads of the science departments concerned.

6. Summary of Investigations Immediately Required.

The following summary of investigations, of course, would involve an organisation far beyond the scope of the Council's present financial resources. All seem important, and the selection of those first to be attacked can be left in abeyance until there is an opportunity of discussion with the investigators concerned.

In drawing up the list of fruit investigations needed, I have received valuable help from the Adviser on Food Preservation, Dr. W. J. Young.

Meat.

1. A study of the storage of beef at temperatures at, or slightly above, the freezing point of the flesh, with a view to exporting it to England in the chilled condition.

2. A study of the freezing, storage, and thawing of bacon pig carcasses with a view to placing them in the hands of the English bacon manufacturer in a condition most suited to the production of bacon and hams of high quality. A subsidiary investigation is also required to specify the type of fat most suited to withstand successfully the storage, transport, and curing processes.

3. An investigation designed to improve the texture and appearance of edible offal exported from Australia in the frozen condition.

Fish.

The time appears inopportune for any investigations to be commenced on the preservation and transport of fresh fish.

Dairy Produce.

The more general investigations required could be carried out most readily by the research officers of the proposed Federal Dairy Industry Research Laboratory.

Fruit.

1. Biochemical studies designed to determine the relationships between chemical and physical constitution of apples, pears, and oranges, and their storage lives. The investigations might well begin with a study of the inorganic and organic phosphates.

2. Further studies on the relationship between maturity at picking and the development of bitter pit and internal breakdown in the chief varieties of apples exported from Victoria and Tasmania.

3. Studies on the relationship between the degree of maturity of pears at picking and the development of "scald" and abnormal ripening.

4. Further studies on the effects on the storage life of apples of additions of nitrogenous, phosphatic and potassium manures to the trees.

5. Studies on the effects of the temperature, composition and relative humidity of the storage atmosphere on the development of the four types of wastage in the four chief varieties of apples exported from Victoria and Tasmania.

6. A critical study of the effects of the temperature of storage on the ripening of pears subsequent to removal from cold storage.

7. Further studies on the storage of grapes, continuing those commenced in Queensland, to determine the chief types of wastage and methods of control, and to widen, if possible, the range of varieties now exported.

Transport and Engineering Problems.

1. Investigations, probably in association with Great Britain, New Zealand, and South Africa, to secure more uniform physical conditions in ships' holds carrying chilled and frozen foodstuffs, particularly fruit.

2. Investigations of the causes of wastage during the transport of tropical fruit by rail from Brisbane to Sydney and Melbourne, and during the transport of apples and pears by steamer from Southern Tasmania to New South Wales and Queensland.

3. When the physical conditions in the storage environment necessary for prolonged storage of beef have been defined, the engineer-physicists will have to design the equipment necessary to carry out the storage on semi-commercial and commercial scales.

4. A study of the physics of, and engineering problems involved in, the evaporation of moisture from foodstuffs in cold storage should constitute one of the chief "long-range" investigations of this section.

7. Plans for Organization of Food Preservation Investigations.

Centralization of experimental work, so desirable for economy and efficiency of operation of scientific research, is impossible in the case of Australian investigations on food preservation; the laboratories must be situated as near as possible to the chief sources of supplies of the experimental material, which are usually widely scattered.

It is possible, however, to conduct all the investigations likely to be required for many years to come in two laboratories supplied with cold storage facilities and situated in Brisbane and Melbourne.

With the limited staff and facilities likely to be available for some years to come, it will be difficult for the section to devote much attention to truly fundamental, but very essential, problems arising from time to time. Yet, without such fundamental data, no edifice of sound investigations can be erected. For instance, until we know more about the metabolism of senescent pears, it is unlikely that the causes of, and methods of overcoming, their abnormal ripening will be discovered. Certain fundamental studies, e.g., the biochemical studies of fruit indicated in the appropriate section of this report, are so essential to future investigations that they must be carried out immediately by the staff. For many other such investigations we must depend on the work of the British Food Investigation Board. As we cannot, however, always be dependent on the latter body, it is suggested that endeavours be made from time to time to have the necessary fundamental investigations carried out by research students working under the senior scientific staffs of the various Australian Universities.

Meat and Tropical Fruit Problems.—The recent offer of the Government of Queensland to provide and maintain laboratory and cold storage facilities at the new State Meat Works on the Brisbane River for the purposes of scientific research, provided that the Council supply and maintain the necessary research workers, adequately provides for all investigations on the preservation of meat.

The State Meat Works have recently been enlarged and modernized to kill cattle, pigs, and sheep, both for the metropolitan fresh meat market and for two meat exporting firms. Provision has been made for killing approximately 700 cattle, 3,000 sheep and lambs, and 1,000 pigs per day. In so large a works, all phases of the meat industry are naturally represented. The laboratory, too, will have the advantage of proximity to Brisbane, where the necessary library facilities and the opportunity to consult other scientific workers will be available.

Any future investigations on the storage and transport of tropical fruits could be concentrated at this Brisbane laboratory. The immediate problems in this field, apart from the transport of the tropical fruits to the southern States, do not seem to be pressing. It will, therefore, be unnecessary to make any elaborate preparations for fruit investigations, and possibly the initial investigations required, at least those involving questions of plant physiology, could be attacked by the staff, whose primary duties will be investigations into the preservation of meat.

The laboratory facilities necessary at Brisbane will consist of space for four research workers (three initially to be employed) with necessary separate space for mycological work. Any routine chemical analyses can be carried out in the works laboratory, which, for the purposes of economy, would be run in conjunction with the research laboratory—the respective staffs, of course, being entirely separate. A small office and library, too, is necessary. It is proposed that the cold storage accommodation be built into an existing chamber. It is believed that at least two small freezing and two medium-size chilling chambers will be required for the meat investigations, and two small chambers for fruit investigations, having a total floor space not exceeding 1,500 square feet.

The staff required for immediate work at the Brisbane laboratory, i.e., for experiments on the chilling of beef, on the freezing of bacon pigs, and on the freezing and storage of edible offal, will consist of a senior investigator in charge of the laboratory and an assistant investigator trained both in biochemical and bacteriological technique. The part-time services of an engineer-physicist, too, will be required for engineering problems arising out of the investigations into the chilling of beef, and for the problem of the transport of tropical fruits to the southern States.

For some time to come, there will probably be insufficient urgent investigations required in the preservation of Queensland fruit to warrant a full-time plant biochemist being stationed at Brisbane.

Non-Tropical Fruit Problems.—Many urgent problems in the preservation and transport of apples, pears, citrus fruits, and passion fruit have been outlined. Melbourne, being close to centres of production of large quantities of these fruits, appears to be the ideal centre of such investigations. It is accordingly suggested that detailed inquiries be made into the possibility of carrying out investigations at this place in conjunction with existing cold storage laboratories.

If the necessary agreements cannot be reached, it is recommended that as soon as funds are available the Council build and equip an experimental station, which, for economy of working, should be attached to a general cold store, and should consist of at least four small experimental cold chambers, each having a floor space of 100 square feet (approximately), a receiving hall for sorting, weighing, and examining fruit, and two laboratories, one for general chemical and physical investigations, and the other for mycological work. Including the cost of all refrigerating equipment (except the compressor and motor) the total cost of such a station with equipment will be of the order of £2,500.

For an adequate study of pre-picking factors, the facilities of experimental orchards should be available. Apart from the value of such orchards for the careful study of the effects of different methods of tree sanitation, cultural practice, pruning, &c., on the size and quality of the yield of fruit, studies, far more carefully controlled than is possible in private orchards, could be made of the effects of variety, root stock, climatic conditions, soil, cultural practice, manuring, and maturity at picking on the subsequent storage life of the fruit. Such orchards and groves are likely, in the future, to form part of the activities of the Victorian and Tasmanian Departments of Agriculture. Arrangements should, therefore, be made by the Council for the Fruit Preservation Research Laboratory to work in close co-operation with the experimental orchards.

Temporary Arrangements for Non-Tropical Fruit Investigations.— It is unlikely that sufficient funds will be available during the next few years to establish a new food preservation laboratory in Melbourne. If the negotiations suggested above fail, there appear to be two alternatives for temporary laboratories.

(*a*) The first alternative is the utilization of the Council's cold storage equipment at the Biochemistry School, Melbourne University, for the chief investigations on apples and pears; and negotiations might be entered into for the chemical and mycological work required to be carried out in the laboratories of the Biochemistry School. The chief objection to this arrangement is the difficulty of securing even approximately constant temperatures in the four small chambers available (each 6 ft. x 3 ft. x 3 ft. approximately). A distinct advantage of such an arrangement would be the central location of the experimental work and proximity to head-quarters, library facilities, and the scientific resources of the University.

(*b*) The second alternative, and one having much to commend it is to locate the investigations on apples and pears in Hobart. (Tasmania is the chief centre of the production of apples and pears for export). There is reason to believe that laboratory and cold storage facilities would be made available by existing organizations in Hobart for the purpose of any experiments the Council may wish to carry out. The capital cost of equipment for the laboratory and cold chambers would be of the order of £300 to £400. If the suggested arrangement in Melbourne be not entered into, it is probable that the work could best be carried out in Tasmania.

The work on citrus fruit and passion fruit could best, of course, be carried out, as before, by the Citrus Preservation Committee, making use of the facilities that have been made available in the past at the Victorian Government Cool Stores.

If any investigations into the storage and transport of fruit are required in New South Wales, facilities would probably be available at a large cold storage works in Sydney, the management of which has made an unofficial offer of cold storage space needed for fruit investigations.

With regard to the work on the cold storage of apples proceeding in Western Australia under the direction of the Council's Division of Plant Industry, the wide differences in the types of soil, cultural practice, and climatic conditions prevailing in Western Australia and Tasmania would enable a close check to be kept on the general applicability of results of experiments in each State. It is suggested, therefore, that the investigations be continued in Western Australia, and, initially, be devoted to a further study of the development of bitter pit in apples, particularly with regard to the effects of the temperature of storage on its rate of development. Experiments on the nature, cause, and control of "water-core" should also be carried out in Western Australia.

The staff required for the fruit investigations (apart from those being carried out in Western Australia) will consist, at least for the first two years, of two plant biochemists of senior and junior status. The senior biochemist should be stationed permanently at the laboratory devoted to problems connected with the storage and transport of apples and pears. For the economical use of the services of the junior biochemist, the latter should assist the senior worker during the period —March to May—in which experiments on apples and pears would be initiated. He would then be available to assist the work of the Citrus Preservation Committee in Victoria during the months July to September and November to February. During the first two years, his services may also be required at various times to assist with the work required to solve the final problems in the transport of bananas from Queensland.

Organization of Transport Investigations.—Until a final decision relating to the scheme for the Empire Refrigerated Transport Survey is reached, the engineer-physicist should be located at the Brisbane Food Preservation Laboratory. An assistant engineer-physicist should be appointed at the completion of the present financial year, both to assist in the transport problems in Australia and to provide continuity of engineering assistance when the senior engineer-physicist is surveying the transport of refrigerated cargoes overseas.

Control of Organization.—Until the time when the Food Preservation Section is constituted as a separate Division, the Council's rather scattered activities in this field would best be co-ordinated by the formation of a Food Preservation Advisory Board which might consist of the Adviser in Food Preservation, the Chiefs of the Divisions of Animal Health and Plant Industry, one representative each from the Meat and Fruit exporting interests, and the Officer-in-Charge of the Food Preservation Section. The functions of this Board would consist in advising the Council in regard to matters of policy, in acting as a clearing house for problems on food preservation submitted to the Council, in forming a link between the scientific work and its application to industry, and, finally, to place adequate facilities at the disposal of the investigators. While the Board may indicate desirable fields for investigations, it *should not* control the detailed programme of research work or otherwise restrict the initiative of the investigators. The Board should meet quarterly.

The control of the Brisbane laboratory should be vested in a committee consisting of the Chairman of the Queensland State Meat Board, the Adviser in Food Preservation, the investigator in charge of the laboratory, and, when fruit investigations are commenced, a representative of the Queensland fruit interests.

Until a laboratory is built for fruit storage work, the co-ordination of the investigations in this field should be carried out by a sub-committee of three members of the Food Preservation Advisory Board, viz., the Adviser, the Officer-in-Charge of Food Preservation Investigations, and a representative of the fruit exporting interests.

H. J. Green, Government Printer, Melbourne.

PAMPHLET No. 24.

COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

The Preservative Treatment of Fence Posts

(with particular reference to Western Australia)

By

J. E. CUMMINS, M.Sc.

MELBOURNE, 1932

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CONTENTS.

FOREWORD.

Australia has been fortunate in its possession of timbers of remarkable durability under general conditions of service. These timbers were at one time plentiful; but as experience showed their value, the demand for them naturally increased. Supplies are in consequence becoming scarcer and prices are rising.

Under these conditions the preservative treatment of less durable species becomes, not only economically possible, but desirable. This is the seemingly inevitable cycle in all timber-producing countries. By the time experience has shown the true value of certain species for particular purposes, the demands of settlement and exploitation of the forests cause a serious depletion in the supply. Fortunately it is possible to treat many less durable species in such a way as to render them highly resistant to the attack of fungi and white ants, and such processes have had tremendous success in other countries.

On a farm there are generally supplies of fence post timbers which, when treated with preservatives, will have a life which may be several times that of the untreated wood. This publication sets out methods of treatment which can be practised by the farmer or other user of fence posts. The plant is cheap, can be easily and quickly erected, and the methods of treatment are simple. What is more important is the fact that by years of experience such treatment has been shown to pay.

In order to obtain data for this pamphlet, about 1,800 fence posts were treated in Western Australia. The work was carried out in co-operation with S. L. Kessell, Esq., Conservator of Forests, Perth, who provided all the material for testing, and who supplied the services of some of his staff to assist in the actual work. The thanks of the Division are due to Mr. Kessell for his assistance and helpful criticism.

Although the tests were made with species of timber growing in Western Australia, the main principles of treatment as outlined can be extended to cover all Australian species. The only probable variable is the time of treatment, and interested persons can obtain information about preservative treatment for their own local varieties of timber by addressing their inquiries to the Division of Forest Products, Council for Scientific and Industrial Research, Melbourne.

I. H. BOAS,
Chief, Division of Forest Products.

21st September, 1931.

SUMMARY.

1. The utilization as fence posts of timbers at present destroyed in clearing farm lands and removed during the forestry practice of thinning is discussed.

2. The main causes of timber deterioration such as decay, damage by termites and borers, and the reasons for differences in the durability of different woods are given in a simple form.

3. The principles of wood preservation, including preservatives of value for fence-post preservation and the different methods for treatment, are outlined.

4. The construction of a simple farm-treating plant and methods of preparing solutions and treating posts are described in detail.

5. Schedules of treatment times for nine species of Western Australian timbers, using both oil and water-soluble preservatives, are given.

6. An estimated cost of treating posts and a discussion of the economy of treatment, together with a suitable method and examples of determining the latter, are presented.

The Preservative Treatment of Fence Posts.

(With Particular Reference to Western Australia.)

1. Introduction.

From the earliest days of farming in Western Australia, the raspberry jam or jam post (*Acacia acuminata*) was recognized as the ideal timber for fencing purposes, and it was used in preference to all others. No reliable estimate of its life can be given, but fences constructed 50 and 60 years ago are still in perfect condition and a life of 50 years is believed to be a conservative estimate. Jam, however, generally grows on good wheat land. In addition to an increase in farming areas in the jam country, which is largely restricted to the localities adjoining the Great Southern Railway and the Midland Railway, the so-called Eastern wheat belt has been developed. This country carries little, if any, jam, the common species of timber being gimlet, salmon gum, boree, morrell, &c. None of these timbers is durable, and jam posts have been used whenever possible. Supplies of jam, however, are becoming scarcer and will become more so in the future. As well as an increased price due to increased demand and reduced supply, the Eastern wheat-belt farmer has to add the cost of freight from the source of supply and the cost of cartage from the railway. As a result of freight charges jam fence posts have been reported to be costing from £4 10s. to £7 10s. per 100 at the siding. At Narrogin and Wickepin the same posts have been quoted at £3 per 100 on siding.

In the clearing of farm lands the present practice is to destroy the greater part of the standing non-durable timber. Yet at very little extra cost fence posts could be cut from this material.

In certain districts, the Forests Department and private companies are growing crops of timbers, in the management of which thinning at definite periods is entailed. These thinnings, in the early development of the forests, would be ideal for fence posts if they could be rendered durable. Moreover, in the case of mallet in the Narrogin district, the forest produce, tannin bark, is ready for stripping when the trees are 5-in. to 6-in. diameter breast high.

The main purpose of this pamphlet is to show how the farmer can utilize his own stocks of timbers for fence posts by treating them with preservatives. It also indicates the possibility of the farmer purchasing untreated thinnings and subsequently treating them on his farm, or of the large scale treatment of thinnings by Government Departments and private companies for retailing to farmers as treated fence posts.

A knowledge of the fundamental causes of timber deterioration and the principles of wood preservation are desirable for a better understanding of the methods outlined later, and a short account of these subjects is therefore presented before dealing with the practical treatment of the fence posts.

2. Causes of Deterioration of Timber.

The main causes of timber deterioration are decay (rot), termites (white ants), other insects, mechanical failure, and fire. Various other causes, such as stock, floods, &c., are not of great importance.

Decay.—Decay is often called dry rot, wet rot, doze or dote. These are not different forms of decay, and are all caused by the action of fungi which are low forms of plant life. The common mushroom, for instance, is a typical fungus. When developed, the portion of the mushroom above the ground consists of a stalk to which is attached an umbrella-shaped, fleshy portion which is called the fruiting body. Below ground the stalk quickly disappears. If a careful search is made, however, thin white threads can be seen running out in all directions from the portion of the stalk in the ground. These white threads are somewhat similar to the roots of ordinary plants, and they extract nutriment

FIG. 1.—Photograph of a highly-magnified piece of wood, showing fungus threads (the small thread-like lines running in all directions in the light-coloured bands) and holes (the smaller irregular-shaped holes, also in the lighter bands) in the wood caused by the fungus.

for the growth of the mushroom from decaying vegetable matter in the soil. An extensive plant system is already developed before the mushroom appears, and this enables the very rapid growth of the edible portion. Wood-destroying fungi, however, instead of living in the ground, live in the timber, and consist mostly of fine threads which penetrate the wood in all directions, and actually absorb certain portions of it. (See Fig. 1.) As these substances are absorbed, the normal structure of the wood is broken down until it becomes soft and friable, i.e., typically rotten.

At times these fine threads grow together to form thick white or pale-coloured sheets generally of a leathery texture. Sometimes, also, the threads grow out to the surface or into a large crack to form masses known as fruiting bodies. These fruiting bodies may be shaped like mushrooms or like brackets (see Fig. 2), or may be quite irregular. They produce millions of small spores (similar in purpose to the seeds of ordinary plants), which, because of their minute size, are easily transported long distances by wind. An example of the number and the size of the spores is given by the common puff ball, which is a fungus. If a ripe puff ball is broken open, a fine powder like a brown smoke spreads everywhere. This powder actually consists of millions of spores. In the case of the wood-destroying fungi each spore, if it lodges on a piece of timber and the conditions are satisfactory, can germinate and set up decay.

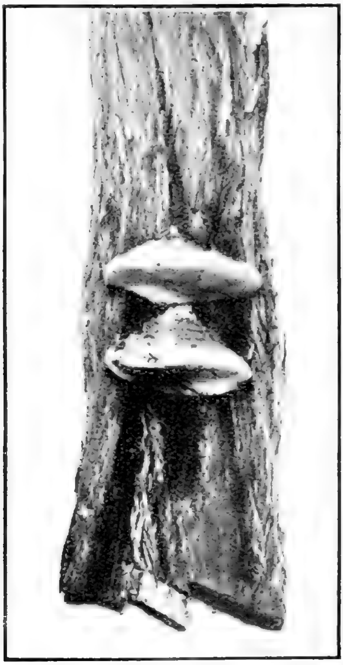

FIG. 2.—Fruiting bodies of a wood-destroying fungus.

Decay can also be conveyed to sound wood by placing it against decayed wood or by allowing small pieces of the fungus threads to come in contact with it. In other words, rot is contagious.

For fungi to develop it is necessary that certain conditions of moisture, air, and heat shall be present together with a suitable food. The moisture required varies somewhat for different species of fungi, but it has been found that excessive moisture on the one hand or a minimum of moisture on the other will prevent growth and hence decay. Thus, wood which is waterlogged, submerged under water, or buried in continually-soaked soil will not decay, while timber which is kept continually dry will also remain free from decay. Fungi need very little air, and it is not possible under ordinary conditions of timber usage to prevent their growth by stopping their air supply. In a fence post, suitable conditions for fungus growth generally exist at the ground line. Here the moisture content of the timber is often that most satisfactory for rapid decay, and the air supply is unrestricted. The range of temperature for the growth of fungi varies somewhat, and at very high and very low temperatures, growth is prevented and the fungus may even be killed. However, the weather is not always too hot or too cold, so that there are times when the temperature conditions are conducive to fungus development. Wood is the suitable food, and as the moisture, temperature, and air supply cannot be controlled in fence posts, the most practical means of combating the decay fungi is by introducing into the wood, preservative materials which are poisonous to them. (See page 15.)

Termites (*White Ants*).—Termites, popularly known as "white ants," are not true ants from the scientist's view-point. Like true ants, however, they live a social life, and in each colony there is a definite division of labour, different work being performed by various forms or castes. Some species of termites build mounds in which the colony lives, and which are very common throughout Australia. (See Fig. 3.) If

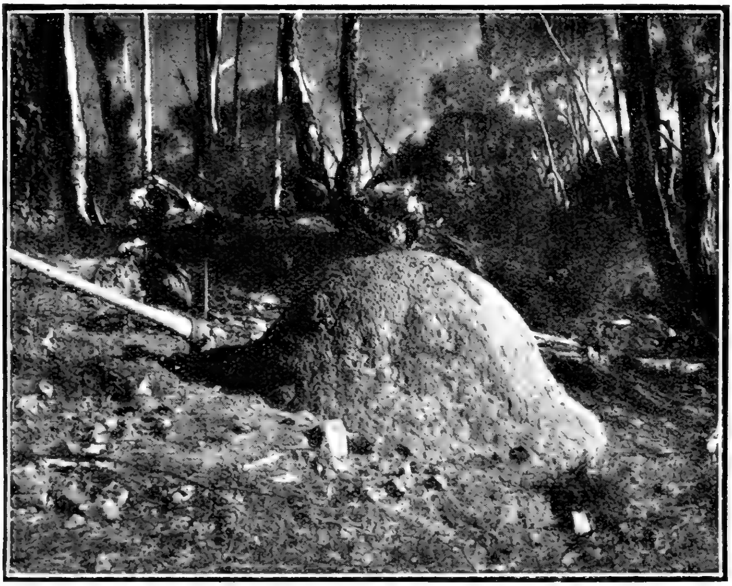

FIG. 3.—A typical termite mound.

Photograph kindly supplied by Mr. G. F. Hill.]

a piece is broken off a termite mound so as to expose the interior, at least two different forms or castes will always be seen. These are the worker and the soldier.

The workers (see Fig. 4) are soft-bodied, white to greyish coloured, blind, and sterile. It is this caste which causes the damage to timber structures by eating and destroying the wood. Workers also build the mounds and communication tunnels, feed the soldiers, the king and the queen, and the young of the colony.

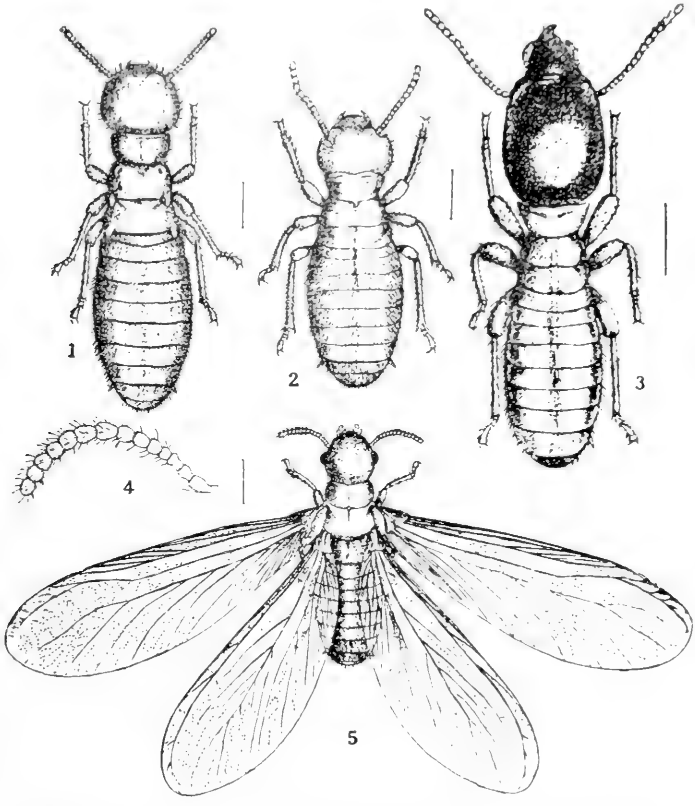

FIG. 4.—Different forms or castes of termites—1. Immature form of winged termite. 2. Worker. 3. Soldier. 4. Antenna of the winged form. 5. Winged form. (Note.—The lines alongside each caste represents the actual size.)

Illustration from Froggatt : "Forest Insects and Timber Borers.")

The soldiers usually are of darker colour than the workers, are blind, have larger brownish-coloured heads, and have jaws especially shaped for defence from attacks by other insects. (See Fig. 4.) In one common group of termites, the head is extended into a long snout and the jaws are undeveloped. From the end of the snout, the soldier can eject a poison to repel other insects. The defence of the colony is the main duty of the soldiers, and it is not unusual to see them prepared to repel intruders by lining all cracks or other openings made in the mound.

Generally, in spring or autumn, long, slender winged forms, popularly called "flying ants," may be found in the colony. They are very ant-like in character, but, unlike the worker and soldier, can see. These are the young reproductive forms, and are either male or female. At certain periods in the year, they may be seen flying from the parent colony in large numbers. If a pair of these flying forms escapes the attacks of other insects and birds and finds a suitable location, it will settle down and form a new colony.

If we break a mound open completely, we may be fortunate in laying bare the royal chamber where live the king and the queen. These are the parents of the colony, and were originally two flying forms. The queen grows to a large size and usually remains in the royal chamber, where she produces enormous numbers of eggs, which are removed by the workers to nearby chambers to hatch into young termites. When first hatched these young termites are called larvae, and are all superficially alike. Later they develop either into workers, into soldiers, or into winged forms. Some termites have the power, if the queen should die or is becoming less prolific in laying eggs, to cause certain of the older larvae to develop into further queens and, if necessary, kings. In some species of termites which do not build mounds, there are no true workers as described above, the work of this caste being performed by larvae and immature stages of the winged form.

The food of termites varies, and they have been reported as living on wood, cellulose, cotton, paper, leather, grass, sugar, horn, bone, seeds, &c.

According to their nesting habits, termites may be broadly grouped into two classes, namely, subterranean and tree dwellers. The subterranean dwellers live in the soil, and often construct mounds on the ground. The tree dwellers never live in the soil or in mounds, and are generally found in galleries tunnelled in growing or dead trees. Both groups are found in Australia, the greater damage to timber structures being done by members of the subterranean group. The discussion which follows refers principally to this group, although some of the information may apply to the tree dwellers.

Termites of the subterranean group need a constant supply of moisture for their successful development, and, therefore, must have a constant contact with the earth. Because of this habit, it is possible to trace the entry of the termites to infested timber above ground. The termites always conceal themselves in the wood, in the ground, or in their communication or shelter tubes. To reach timber not in contact with the ground, they may enter through cracks in cement floors or brickwork (as in a house), through heart pipes or cracks in wooden-house foundation blocks, or else they may build their covered runways over any convenient surface. (See Fig. 5.) Damage above ground level may, therefore, be prevented by ensuring that no access cracks, &c., are present, by periodically breaking down any runways that may be formed over the surfaces, and by suitable treatment of the surrounding soil. Special termite insulators can also be used to prevent the building of runways over exposed surfaces.

Infestation of sound timber can occur by two main methods. A termite colony which might be in the vicinity may extend its galleries to the sound timber and attack it, or the sound timber may form a suitable place for the development of a new colony by the flying reproductive forms.

Damage by termites can cause large losses of timber, and prevention of this is sometimes difficult. In the case of fence posts, the only practical method is by the use of durable woods or preservative treatment in which the non-durable wood is rendered immune from attack.

Borers.—The main types of borers likely to cause damage to hardwood fence posts are the powder post borer and the auger borer. The greater part of the damage to the timber is done below the surface by the undeveloped beetle or grub form. This grub form develops into the beetle, which immediately commences to bore its way out of the wood to the surface. Where it emerges, small round holes can be seen. Generally, the attack is confined to the sapwood only, especially in the case of the powder post borer. The auger borer, however, may extend its attack to the truewood* (or heartwood) of the post.

FIG. 5.—Termite communication tubes on concrete pile.

Photograph kindly supplied by Mr. G. F. Hill.]

Softwood or pine posts may be attacked by a species similar to the so-called furniture borers. This borer will attack both the sapwood and the truewood (heartwood).

The extent of damage to fence posts by borers is thought to be small and no evidence has been obtained of posts having to be replaced because of their damage. Prevention of attack would be possible by completely treating the post with preservatives as detailed later, but the expense does not seem to be justified as a safeguard against borers alone.

Miscellaneous Causes.—Effective fireproofing of fence posts is not economically practicable, and no precautions can be taken against

* The term "truewood" has been adopted to describe what is usually termed heartwood. In Australia, the central portion of a tree is very often affected by decay or has little strength. This portion, which is really part of the heartwood, is called "heart". The terms "heart" and "heartwood" are therefore confusing, and that portion of the tree between the "heart," or the pith, and the sapwood has been named the truewood.

floods, lightning, &c. Mechanical failure may be due to using fence posts of too small a diameter and can be corrected by increasing the size or by using a stronger species.

3. Durability of Australian Timbers.

The durability of timber from different species of trees varies widely. One species, such as jam, will be very durable, whereas another such as mallet will be non-durable. The results of chemical and laboratory tests on durable and non-durable timbers have shown that the durable timbers contain substances which are poisonous to fungi, whereas the non-durable ones have a much less quantity of such substances or none at all. In some cases the poisonous material is an oil; in others it is probably a solid material.

Sapwood and Truewood.—The sapwood or outer part of a tree, which is usually of a lighter colour than the truewood, is chemically different from the truewood in that it does not contain substances which are poisonous to fungi or termites. As a result, sapwood does not resist decay or insect attack. A common practice in Australia is to remove the sapwood from poles and posts at and near the ground line. This practice undoubtedly prevents the more rapid attack of truewood, but it also considerably reduces the effective diameter of a pole or post, and, as the sapwood and truewood have for these practical purposes the same strength, it would be desirable to retain the sapwood. Sapwood generally is much more easily treated with preservatives and, as will be shown later (p. 18), it is particularly desirable to retain it on treated posts or poles.

Conditions of Growth.—Fast-grown, young timber is frequently less durable than slow-grown, mature timber. This difference is important in the use of untreated timber, but, with effective preservative treatment, a fast rate of growth may even become an advantage, provided the younger, fast-grown material does not "pop" or split excessively either before or after treatment. Young, fast-grown material has usually a wider sapwood and a more easily penetrated structure.

Influence of Locality.—It is a popular belief that timber should be used in the locality in which it was grown in order to obtain the maximum life possible. In some cases, evidence tends to show that this is correct, but there are other factors which are much more important. The chief of these is the possibility of infection by organisms of decay or by insects being greater in one district than in another. This is shown in Western Australia. In the South-West, and in areas with an annual rainfall of more than 15 inches, the main cause of renewal of timbers is decay. In the Eastern wheat belt, and farther East and North where the rainfall is less than 15 inches annually, the decay of timber is less, but the severity and frequency of termite attack increases.

Soils, too, have an influence on durability. For instance, in soils which are continually wet the water-logged condition of the post at the ground line reduces the possibility of decay. The experience of farmers in Western Australia tends to show that in some localities there is less attack by termites on typical sandy soils than there is on those of a loamy nature. Decay can also be expected to be less serious in well-drained sandy soils.

Time of Cutting.—Contrary to the popular belief that trees should be cut only when the sap is down, the time of cutting has no effect on the durability, provided that proper care of the posts is subsequently taken. Actually there is no such state as the sap being " up " or " down " throughout a tree. Numerous tests have shown that the amount of sap in a tree trunk does not vary from winter to summer, and as a result there is no advantage to be gained in more rapid seasoning, &c. On the other hand, the influence of the seasons of the year on the rate of drying is an important factor. Very rapid drying of fence posts, especially those cut from young trees, causes an excessive number of cracks and splits. In the drier parts of Australia, felling in the winter is thus an advantage, provided the posts are immediately stacked properly (see p. 19). If the posts are cut in the winter, drying is not so rapid, but by the summer a large amount of drying will already have taken place. At the end of the seasoning period such posts will have less splits and cracks than those cut and stacked the same way in the summer.

4. Principles of Wood Preservation.

As has been stated, the development and growth of fungi require certain conditions of air, moisture, and temperature, and a suitable food. Obviously, control of the supply of air, moisture, or temperature is not possible for fence posts. The only factor that can be controlled is the food, namely, the wood. Insects, too, require certain conditions of air, moisture, and temperature, and control of their food is generally the only possible practical method. Certain woods are durable because of the presence of poisonous substances. If, therefore, materials which are poisonous to decay and insects are placed into non-durable woods they will be converted into durable ones. Wood preservation treatments are designed to introduce materials which will render the wood poisonous, and thus prevent the growth of fungi or insects. It is not necessary to penetrate the wood completely with preservatives, but only to provide a continuous outer layer of impregnated wood. In some cases this layer should cover all surfaces of the treated timber; in others (as in most cases of fence posts) it is only necessary to treat that portion to be placed in the ground and just above the ground line.

5. Preservatives.

There are large numbers of preservatives which have been, or are being, advocated for use. They may be broadly divided into two groups, namely, oil preservatives and water-soluble preservatives. Only those of particular value and interest for the preservation of fence posts in Australia at the present time will be discussed.

(*a*) *Oil Preservatives.*

Coal-tar creosote is an oil prepared from coal-tar. The results of extensive tests and of experience in other countries have shown that this oil is the most effective for general purposes. It is, however, dark coloured, and has a distinct odour, both of which may in some cases be undesirable. Creosote oil varies considerably in quality, but any good grade oil will give good results, provided there is sufficient of it introduced, and that the penetration of the oil into the wood is satisfactory (see Appendix 1).

Tar is often used for brushing or painting the ends of posts, &c., but it is of very doubtful value. It is much less poisonous to fungi and insects than is creosote and its penetration into the wood is less than with creosote used under the same conditions. Its use is not recommended.

Petroleum Oils.—These are not sufficiently poisonous enough to fungi to prevent decay, and their use for prevention of insect attack cannot at present be recommended.

Creosote and Oil Mixtures.—Where the cost of creosote is high, it is an economy to dilute it with a petroleum oil. Naturally, pure creosote is more satisfactory, but creosote, if of a good grade, is generally sufficiently poisonous to withstand some dilution with non-poisonous oils. The use of the crude oil lowers the cost of the preservative or for the same expense provides a better distribution of the creosote in the wood. The best oil for dilution is crude petroleum, or a light fuel oil which may be added to form a solution consisting of *2 parts of creosote to 1 part of oil.* The treatment schedules given on p. 24 were obtained by using this mixture.

Patented or Proprietary Oil Preservatives.—There are a number of these available; some are good and some are of doubtful value. They are usually more expensive than ordinary creosote and any one proposing to use them should make thorough inquiries, and if possible ask for advice from the Division of Forest Products.

(*b*) *Water-Soluble Preservatives.*

The principal water-soluble preservatives available for use in Australia at present are sodium fluoride, zinc chloride, and white arsenic (arsenic).

Sodium fluoride is a white powder which is soluble in water, about 4 lb. of it dissolving in 10 gallons of water at ordinary temperatures. It is very poisonous to fungi, but not to termites. The use of white arsenic, in addition to the sodium fluoride, is therefore necessary (see p. 24).

Zinc chloride is sold in a solid form or in a heavy concentrated solution containing about 50 per cent. zinc chloride. It is very soluble in water. Like sodium fluoride, it is very poisonous to fungi, but not to termites.

White arsenic (also sold commercially under the name "arsenic") is a whitish powder which is slightly soluble in water, about 2 lb. of it dissolving in 10 gallons of water at ordinary temperatures. It is not easily dissolved in water unless the solution is boiled vigorously, because the white powder floats to the surface and is difficult to wet (see p. 23). Experience over a large number of years has shown that white arsenic is a very effective poison against termites. Where both fungi and termites are likely to attack the timber, a solution containing white arsenic with either sodium fluoride or zinc chloride is recommended. In the drier localities, it is possible that treatment with white arsenic alone would be effective, and experiments are now being made to test this belief.

Patented or Proprietary Water-soluble Preservatives are available sometimes in powder form and sometimes in solution. Usually, the actual composition of these preservatives is not given, and as their value varies considerably, any one proposing to use them should fully investigate their efficacy first.

6. Methods of Treating Timbers.

The objective in the treatment of timber is to introduce the preservatives into the wood so that a deep layer of preserved wood and a sufficient quantity of preservative to prevent decay and termite attack is obtained. The following methods are generally used:—

Pressure Processes.—These methods involve the use of a large specially constructed preservation plant. The timber to be treated is loaded on special trucks and is run into long steel cylinders which are then closed. Depending on the actual process to be used, the timber is first subjected to a vacuum or to air pressure, the cylinder is then filled with solution, and pressure is applied until the wood absorbs the required amount of solution. A final vacuum treatment is then often given. Where facilities are available this is the most satisfactory method for treating wood. It is not at present in use in Australia.

Open Tank Process.—For use on the farm with its natural limitations, the open tank process is the most satisfactory and practicable (see Fig. 8). The timber to be treated is placed in a tank of hot preservative and heated therein for some hours. During this heating period the air which is present in the cells of the wood is heated. It thus expands, and some of it is in consequence expelled. At the end of the heating period, the timber is either quickly removed to a separate tank containing cold preservative or else it is left to cool down in the same tank. During this cooling period, the remaining hot air in the cells cools and contracts, and the preservative is sucked in.

Generally, for the treatment of fence posts, only that portion of the post inserted into the ground, plus a further 6 inches to show above the ground, is inserted into the preservative.

Only seasoned or dry timber can be satisfactorily treated by this method. Except for timber which is very easily treated, there is practically no absorption of preservative during the heating period. All absorption takes place during the cooling or cold bath treatment. If too much preservative is being absorbed by the wood, the duration of the cooling treatment can be shortened. By increasing the length of time of the heating period, it is possible, up to a certain limit, to increase the penetration of the preservative. Full details and times of treatment are given on pages 24 and 25.

Steeping Process.—This is used with water solutions only, and consists of soaking the dry wood in the cold solution, preferably for some weeks. On account of the long time required for treatment, and the fact that good penetration and absorption of the preservatives are not usually obtained, its general use cannot be recommended.

Dipping Process.—This consists of placing the seasoned fence posts in the hot preservative solution for a short period—generally five to fifteen minutes. Very little penetration and absorption of preservative into the wood occurs, although all surfaces and cracks are generally well coated with the preservative. Only oil preservatives should be used with this process. With water solutions, the thin coating so obtained is easily washed off by rain, and so their use is not advocated. As the preserved layer of wood is very thin, and the amount of preservative absorbed very small, long life cannot be expected from timber so treated. The treatment probably justifies the expense, and is advantageous in that large numbers of posts can be quickly treated at a relatively small cost.

Brushing Processes.—These consist of brushing, painting, or swabbing the preservative into the timber. Only oil preservatives are satisfactory for this purpose, and they should be brushed on hot, preferably at about 200°F. Every care should be taken to ensure that the oil is forced into all cracks or defects in the wood. Several coatings should be applied, each coating being allowed to dry before the next is commenced. The use of hot oil allows the cracks, &c., to be more easily treated. The method is not as satisfactory as dipping, and good results should not be expected from its use. It is cheap, and large numbers of posts can be quickly treated with a minimum of preservative. Only well-seasoned wood should be used, because, with green timber, further cracks will occur on drying, and these will immediately expose untreated wood. Fence posts should be painted in order to coat the portion being placed in the ground, together with a further 6 inches above the ground.

Brush treatments are of value for those parts of a construction which cannot be treated by other means; for re-coating treated portions which have been cut into for erection purposes; or for coating contact points where decay is likely to occur.

7. Absorptions and Penetrations Necessary for Effective Treatment.

The effectiveness of any preservative treatment depends upon having a continuous, unbroken, outer layer of preserved wood containing a sufficient quantity of preservative to prevent fungal and insect attack. Experiments in the preservation of Australian timbers for fence posts have shown that the penetration in the truewood of split posts is very small—generally less than $\frac{1}{8}$ of an inch. The sapwood is more easily treated, and by the open tank process complete, or almost complete, penetration can be obtained. With all the Western Australian species except gimlet, the sapwood is usually $\frac{1}{2}$ of an inch, or more, in thickness, and this can be effectively treated. In gimlet, the sapwood is generally less, but it takes treatment fairly well. A depth of $\frac{1}{2}$ an inch of unbroken treated wood is regarded as a very satisfactory protection.

The necessary amount of preservative varies with the preservative and the type of attack expected. Using a mixture of 2 parts of creosote to 1 part of fuel oil a 4-in. butt diameter fence post, if treated to a height of 2 ft. 6 in. from the butt, should absorb about $1\frac{1}{2}$ lb., a 5-in. post about 2 lb., and 6-in. post about $2\frac{1}{4}$ lb., of preservative. This quantity is equivalent to 7 lb. of creosote and oil mixture per cubic foot of wood which is treated, i.e., per cubic foot of post for 2 ft. 6 in. from the butt. Experience in other countries has shown that with zinc chloride and sodium fluoride, about $\frac{1}{2}$ lb. of dry salt is needed per cubic foot of wood in order to prevent decay. In Australia, about $\frac{1}{4}$ lb. of white arsenic per cubic foot has been found effective against termites. Using solutions containing $3\frac{1}{2}$ per cent. sodium fluoride or $3\frac{1}{2}$ per cent. zinc chloride together with 2 per cent. white arsenic, a 4-in butt diameter fence post should absorb about 3 lb., a 5-in. post about 4 lb., and a 6-in. post about $4\frac{1}{2}$ lb of solution (1 gallon of solution weighs about 10 lb.). This is equivalent to about 14 lb. of solution per cubic foot of wood. With water solutions, on account of the possibility of their being washed out by water, it is advisable to treat the timber so that it absorbs as much solution as possible.

8. Practical Treatment of Fence Posts.

Preparation of Fence Posts for Treatment.—For all the preservative processes discussed, proper seasoning before treatment is essential in order to obtain good results. There are two reasons for this. Firstly, in green timber the wood cells are either completely or partially filled with sap—which is mainly water. On drying, this water is removed from the wood and thus a space is formed which can be used for the introduction later of preservative liquids. The more of this moisture removed, the more space there will be for preservatives to enter. Secondly, when wood dries, especially in the form of round posts, it usually cracks, the cracks extending some distance in from the surface. If the posts are treated before these cracks develop, then, on drying, cracks will extend through the treated area and expose untreated wood. They will therefore allow termites and decay to gain entry to the untreated wood in the centre of the post. If the posts are first dried, these seasoning cracks are formed before treatment, and, as a result, the surfaces of each crack are thoroughly treated with preservative, and the entrance of decay or termites to the untreated wood in the centre is prevented.

As soon after felling as possible, the posts should be barked, care being taken to remove *all* the bark from the portion that is to be treated. In the case of *Pinus radiata* (*insignis*), a very thin inner bark often adheres very strongly to the wood. This thin inner bark often prevents penetration of the preservative, so every care should be taken to remove it from the portion to be treated. In the case of jarrah and redgum (marri), it has been found that small amounts of the inner white bark do not appear to affect the penetration but, as an added precaution, they should be removed.

For seasoning, a site should be chosen that will allow prevailing winds to blow through the stacks. For preference, the site should be on high ground, and should be well drained. In building the stack, care should be taken to have good foundations which will raise the stack about 1 foot off the ground (see Fig. 6). In cases where no suitable foundations are available, large fence posts can be used as a base. In bad termite localities, frequent inspection of the base of such a stack is necessary, because termites have been found to build their way over foundations and to attack the posts within a very short time. Provision for efficient air circulation should be made by providing a space between posts. A good method of open piling is shown in Fig. 6. Only three posts are used in each alternate layer; the other layers, with the posts at right angles to the first, have from five to ten posts. The number depends on the length and diameter of the posts, but each post in these rows must be carefully separated from its neighbour. It is sometimes possible to obtain more rapid seasoning by increasing the width of the space between posts, but if this is done in the summer time, frequent inspection of the stacks should be made to see that they are not cracking too severely. If this occurs, the posts should be placed closer together. A better method to use with timber which cracks excessively when quickly seasoned is to cut and stack the fence posts in the winter, when the drying of the timber is much slower, and there is less tendency to crack. By summer time, the timber will be partially dried and less liable to develop further cracks. Barking will also be found to be easier in the winter.

To obtain good treatment results, posts should be air-seasoned for about six months, and treated during a period of dry weather, unless arrangements can be made to stack the seasoned posts under cover in a shed. Under no condition should posts which have been recently wet by rain be treated. In the Eastern wheat belt of Western Australia, posts cut at the end of winter or in the spring should be ready for treatment at the end of summer.

The stacking of untreated posts, particularly green ones, in a close stack, as shown in Fig. 7, is bad practice, and decay or termite attack is very liable to occur before treatment.

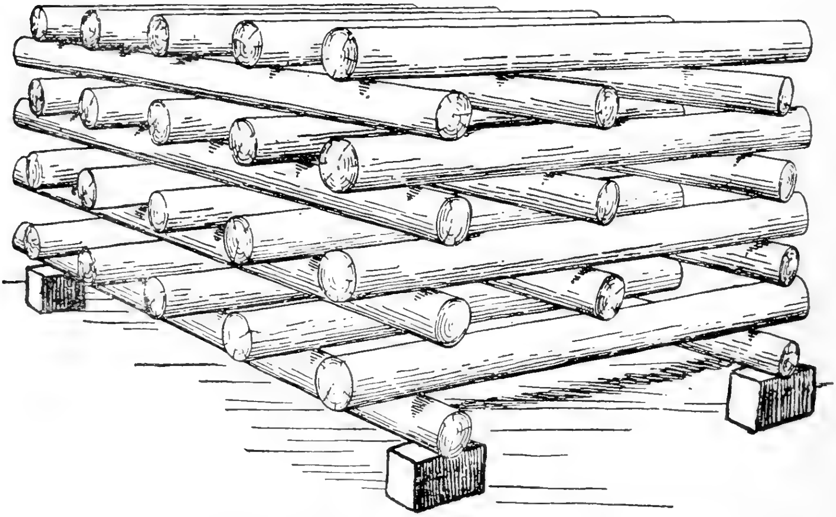

FIG. 6.—A good method of piling fence posts for seasoning.

FIG. 7.—A badly piled stack of fence posts. There is very little drying in such a stack, and conditions are very suitable for both decay and termite attack during storage.

Construction of Farm Treating Plant for Butt Treatment by the Open Tank Process.—The essential plant required consists of one or more treating tanks, the number depending on the amount of material to be treated, and a thermometer. Provision should be made for heating at least one of the tanks.

For the farm treatment of ordinary 5-ft. to 6-ft. fence posts, which are generally set to a depth of 18 inches to 22 inches, the cheapest and most easily obtained tank is the ordinary 45 gallon oil drum. These drums measure 34 inches deep by 22 inches diameter, and will permit treatment of the butt ends of the posts to a height of 2 ft. 6 in. Where a longer length of treated material is required, any tank which is sufficiently strong to hold the posts and solution, which is free of leaks, and which can be satisfactorily heated, will be suitable.

A very satisfactory and easily-handled unit consists of four drums for treating, together with one or two extra drums for storage of solutions. The tops of the drums should be removed, and the insides wiped clean with waste cloth. Two of the drums are required to be heated and fireplaces should be constructed for these. Some provision should be made for reducing loss of heat from the fire. A suitable arrangement is shown in Fig. 8. The two drums in the foreground are the heating

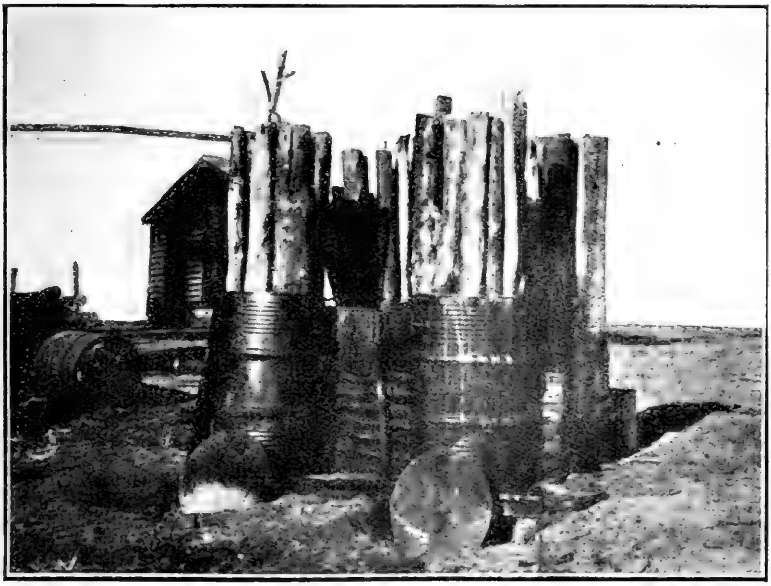

FIG. 8.—A simple fence post treating plant for use on the farm.

drums, and those in the background, the cooling drums. In this case, two short lengths of old rail were used as supports, and the fireplaces were excavated slightly. The tops of the drums were used for dampers, and old pieces of galvanized roofing iron and flattened petrol tins were used for protecting the fire from the wind.

The best thermometer is a mercury thermometer reading in degrees Fahrenheit (°F.) with a temperature range up to 240°F. These cost about 3s. 6d.

If it is desired to maintain close control of the water solutions, a special hydrometer can be used (see Appendix 2).

Details of Butt Treatment Using Creosote and Oil.—The creosote and oil mixture is prepared by thoroughly mixing together *2 parts of creosote to 1 part of crude or fuel oil by volume.* For the preparation of 45 gallons of the mixture, 30 gallons of creosote should be thoroughly mixed with 15 gallons of oil. When using 3-in. to 4-in. average butt diameter posts, fill each drum to about the 18-in. mark, i.e., add about 25 gallons of preservative solution. Usually, it is preferable to have a little less oil than will be actually required, as it is easier to add than to remove hot oil from the drums. For convenience, a distinct mark should be made on the outside of the drum corresponding to a height of 2 ft. 6 in., the length of post to be treated. The oil in the drums over the fires should be heated until a temperature of about 200°F. to 210°F. is reached. The posts should then be placed vertically in the drums, butt down, **care being taken not to splash the oil mixture into the fire.** When the drum is full of posts, the height of the preservative in the drum should correspond with the 2 ft. 6 in. height mark. If it does not, oil is added or taken from the drum until the required level is obtained. Heating of the drum and its contents is continued and the temperature noted. The oil should not be heated above about 210°F. as temperatures above this cause considerable loss of preservative by evaporation. When the heating period for the species being treated (see Table 1) is completed, the posts are quickly removed from the hot drum and placed in the cold drum immediately behind or alongside it. This cooling drum should contain about 1 ft. 6 in. depth, or about 25 gallons of solution. The heating drum can be refilled with posts and the heating continued as before. In each case, the time of the heating period is calculated from the time that all of the posts are placed in the hot oil. If the species of timber being treated requires a 4 hours' heating period, only two sets of treatments per day would probably be practicable. In this case, at the end of the heating period for the second treatment, the posts can be left in the drum and the fire drawn or allowed to burn out and the drum and its contents allowed to cool overnight. It is during the cooling period that the main part of the penetration and absorption of the preservative by the wood occurs. In the early part of the cooling, this is more rapid and the level of solution in the cooling drum and heating drum during cooling should be watched and more oil added from the storage supply to keep the oil to the 2 ft. 6 in. level. The posts should be removed from both drums the next morning, and the solution in the hot drums re-heated in readiness for further treatments.

With some types of creosotes it will be found after overnight cooling, particularly in cold weather, that the creosote and oil mixture in the treating drums is very thick and sticks to the posts when they are removed. This thick surface coat is an actual loss of preservative, it also makes the posts very dirty to handle, and it will run off in the stacks or sheds or wherever the treated posts may be kept until use. In such cases, the posts should not be removed until the oil has been warmed. Similarly, the posts in the cooling drums can be allowed to stand several hours longer, depending on the time of treatment being used, until they are warmed up by the surrounding air or sun, or else they can be removed from the cooling drum and dipped in the hot oil for a few minutes and then removed to the stacks.

When heating the posts in the oil, care should be taken not to use too large a fire as there will be danger of the oil boiling over. If this does happen, it is probable that the oil and posts in the treating drum will catch fire. The rate of heating of the oil can be followed by using the thermometer at regular intervals. Approximately one hour is usually required to heat the oil alone to 210°F. using a good fire. Placing the posts in the drum cools the oil, but once the temperature is again reached, a very small fire is sufficient to keep it heated. With a little experience the fire can be easily regulated so that a minimum of attention is required.

In the instructions given above the posts are placed in the hot solution. This method has been found to be very convenient, but, if it is more practicable, the posts can be placed directly in the cold solution and heated up at the same time. If this is done, the drums will require closer watching to prevent heating above the temperature of 210° F. with the attendant danger of boiling over.

In the treatment of pine posts or the less dense hardwood timbers, it will be found that the posts float in the solution, and some difficulty is experienced in setting them upright in the drums. This can be corrected by constructing a false bottom, which can be made from the top of the drum by nailing wooden strips or riveting iron strips on one side. Screws or nails are inserted into the strips so that they protrude upwards about ½ inch to ¾ inch in height. The false bottom is placed in the bottom of the treating drum so that the protecting nails or screws point upwards.

Details of Butt Treatment, using Water Solutions.—When using the water solutions discussed below, it is advisable to erect a further drum—apart from the treating drums—for preparing solutions, particularly if large numbers of posts are to be treated. This drum should be erected over a suitable fireplace.

Zinc Chloride and White Arsenic Solution.—Zinc chloride can be purchased as a solid, which is about 100 per cent. zinc chloride, or in a solution with water containing about 50 per cent. zinc chloride.

In order to make 40 gallons of preservative solution, the 45-gallon oil-drum is filled to a height of 2 ft. 2 in. with cold water. A mark should be made at this height. To the water is added 14½ lb. of solid zinc chloride or the equivalent amount of the concentrated zinc chloride solution. Add 8½ lb. of white arsenic and heat the drum to boiling. Boil vigorously until all the arsenic is dissolved, which should take about 30 minutes. It will be found that the white arsenic will rise to the surface, and will be difficult to wet by stirring, but good boiling and stirring will soon dissolve it. During the boiling, water should be added to make up for evaporation, and after cooling, if the solution height is below the 40-gallon mark (2 ft. 2 in.), it should be made up by again adding water.*

The treatment of the posts is carried out similarly to that with creosote, except that the solution is brought to the boil and the posts boiled in the solution according to the schedules given in Table 2. As water evaporates quickly from the boiling solution, more attention is

* To obtain the density or strength of this solution, allow it to cool, and either place the hydrometer in the solution drum or in a separate container filled with the solution. The temperature of the solution should be taken together with the reading of the hydrometer (see Appendix 2).

required, and water only should be added to the treating drum to make up for the evaporation. At the end of the heating period, the posts are allowed to cool in the solution, either by remaining in the treating drum or by being quickly removed to a drum of cold solution. On cooling, absorption of solution takes place, and there is much more water solution absorbed than creosote and oil under similar conditions. To make up for the solution absorbed by the posts, fresh solution is added from the solution storage drum, so that the treating liquid is kept up to the height of 2 ft. 6 in. marked on the drum.

If care is taken to add *water* to the treating drum to make up for the evaporation while the posts are being boiled, and if *solution* is added during the cooling and absorption period, the strength of the treating solution will remain fairly constant. (See Appendix 2.)

White arsenic is a poison, and every care should be taken while using it. (See Appendix 3.)

Sodium Fluoride and White Arsenic Solution.

Sodium fluoride and white arsenic are both bought in powder form.

In order to make 40 gallons of solution, the 45-gallon oil-drum is filled to a height of 2 ft. 2 in. with cold water. A mark should be made at this height. To the water 14½ lb. of sodium fluoride and 8½ lb. of white arsenic are added. The contents of the drum should then be heated to boiling and boiled vigorously for about 30 minutes or until all the chemicals have dissolved. (See instructions for zinc chloride and white arsenic solution.)

The treatment of posts, using the sodium fluoride and white arsenic solution, is exactly the same as for the zinc chloride and white arsenic solution, and the same instructions should be followed.

Schedules of Treatment.

With the species of timber tested in Western Australia, the schedules given in Tables 1 and 2 have been found to give the best results.

TABLE 1.—SCHEDULES FOR THE TREATMENT OF ROUND FENCE POSTS WITH CREOSOTE AND OIL MIXTURE.

Timber.	Time of treatment.	
	Hot bath.	Cold bath.
	hours.	
Brown Mallet	4	Overnight
Gimlet	4	,,
Goldfield's Redwood	4	,,
Jarrah	3	,,
Marri (Red Gum)	4	,,
Morrell	4	,,
Salmon Gum	4	,,
Pinus radiata (insignis)	1½	3 hours

TABLE 2.—SCHEDULES FOR THE TREATMENT OF ROUND FENCE POSTS WITH WATER SOLUTIONS SUCH AS ZINC CHLORIDE WITH WHITE ARSENIC AND SODIUM FLUORIDE WITH WHITE ARSENIC.

Timber.	Time of treatment.	
	Hot bath.	Cold bath
	hours.	
Boree	4	Overnight
Brown Mallet	3	,,
Gimlet	4	,,
Goldfield's Redwood	4	,,
Jarrah	3	,,
Marri (Red Gum)	2	,,
Morrell	4	,,
Salmon Gum	4	,,
Pinus radiata (*insignis*)	2	,,

Top Treatment of Fence Posts.

The treatments so far outlined have been for the butts of the posts only. In the case of wood of very low durability, it is often advisable to treat completely the whole length of the post, so as to prevent any possibility of decay or insect attack above the ground. With such untreated wood, decay is particularly liable to occur at the junction of fence rails or in the holes for the wire. Complete full-length treatment is not at present economically justified under Australian conditions, since the cost of treatment is considerable. If further information is required relative to the type of plant and costs, this can be obtained by reference to the Division of Forest Products.

For *Pinus radiata* (*insignis*) it appears that a light top treatment in conjunction with the butt treatment outlined previously will be justified. This can be done after butt treatment by inserting the posts top down in a drum of hot preservative and allowing them to stand in the hot oil for about five to ten minutes. For a post longer than 5 feet there will still be an untreated length, and this should be swabbed with hot preservative several times. Alternatively, the length above the treated butt could be brush-treated with hot preservatives.

Such top treatment is of value only so long as the thin layer of treated wood is kept unbroken. If posts are checked for rails or holes made for the wires, the untreated wood so exposed should be thoroughly brushed with preservative solution, which should be applied hot whenever possible.

9. Care of Treated Timber.

Butt-treated fence posts, if not intended for immediate use, should be carefully open piled in a similar manner to that detailed for seasoning, except that in this case the posts may be placed somewhat closer together in the layers. If this is not done, and the posts are bulk piled on the ground, there is considerable danger of decay or termite attack developing in the untreated tops, particularly in the case of non-durable timber.

Care should also be taken to ensure that the treated area of wood is not knocked off, thus exposing untreated material. Similarly, if it is necessary to cut into the treated zone in the construction of the fence line, all untreated timber so exposed should be brush-treated several times with preservative.

In the treatment of the post, provision was made for a preserved portion to remain above ground level, and when setting the posts care should be taken that at least 6 inches of treated wood is exposed above the surface.

10. Cost of Treatment.

The cost of treatment of fence posts will vary somewhat according to local conditions and to various items which, in some cases, may be considered directly chargeable to the treatment and, in others, not chargeable. The items of material and labour are listed below, and persons considering treatment can adjust their estimates of cost according to their conditions.

1. *Cost of Untreated Posts.*

Normally, on farms requiring considerable fencing, there are areas which are to be subsequently cleared, and which carry supplies of timber which can be made suitable for fence posts. Round posts are necessary for best results, and posts from about 3 inches to 6 inches diameter will be found satisfactory for use.* Actual costs of cutting, barking, and piling for seasoning in stacks close to the falling site averaged 25s. per 100 posts (labour at 16s. per day of eight hours) for experimental work in the eastern wheat belt. With experience in cutting and barking, these costs could be reduced to about £1 per 100; and in the case of post cutting and barking, in conjunction with clearing operations, the cost should be lower again. Generally, the time of barking is about equal to the time of felling and cutting to lengths. In the case of pines, the removal of the bark is more difficult, and the average cost per 100 barked posts would be about 25s.

2. *Cost of Plant.*

Forty-five gallon oil-drums are now common articles, and are available in almost all country centres. The average cost of drums suitable for treatment is at present about 4s. to 5s. each. A treating plant, consisting of two heating drums, two cooling drums, and a solution drum, would therefore cost about £1. The fireplaces can generally be made from old iron, bricks, or stones, and to make them should not occupy more than an hour or two.

3. *Cost of Preservatives.*

The cost of preservatives varies somewhat according to market prices. The prices quoted hereunder are approximate only, and for Western Australia freight rates, as per Table 3, must be added to them.

Creosote.—Creosote varies considerably in price according to its grade and source of supply. A good grade creosote for wood-preserving purposes would cost about 1s. 9d. per gallon, f.o.r. Perth, in 45-gallon containers.

* If split posts are treated only the sapwood will be well penetrated. While, therefore, the treatment will not be as effective as with round posts, where the latter are unavailable, it will probably be justified.

Fuel Oil.—Fuel oil can be obtained at 5d. per gallon, f.o.r. Fremantle, in 45-gallon drums. The drums are returnable, but are charged for at the rate of 5s. each. They would be suitable for treating drums.

Sodium Fluoride.—Sodium fluoride in solid form will cost about 5d. per lb. f.o.r. Perth in cwt. lots.

Zinc Chloride.—Zinc chloride in 50 to 55 per cent. solution will cost 3½d. per lb f.o.r. Perth in cwt. lots. It must be remembered that this solution only contains about half its weight of zinc chloride so that the cost of the solution at the farm should be multiplied by two to give the approximate cost of the pure zinc chloride.

White Arsenic.—The price of white arsenic is about 5d. per lb. f.o.r. Perth in cwt. lots.

TABLE 3.—FREIGHT RATES ON PRESERVATIVES, WESTERN AUSTRALIA.

Preservative.	Freight Rate. (Small quantities.)		
	100 miles.	200 miles.	300 miles.
Creosote ..	Per 45-gal. drum—about 10s.	Per 45-gal. drum—about 15s.	Per 45-gal. drum—about £1
Crude Oil ..	Per 45-gal. drum—about 10s.	Per 45-gal. drum—about 15s.	Per 45-gal. drum—about £1
Sodium fluoride	3s. 9d. per cwt.	5s. 6d. per cwt.	7s. 6d. per cwt.
Zinc chloride ..	5s. 6d. per cwt.	8s. 9d. per cwt.	12s. per cwt.
White arsenic..	4s. 6d. per cwt.	7s. 6d. per cwt.	10s. per cwt.

Fuel.—The only charge for fuel on most farms will be the cost of collection. For two 4-hour boiling periods in the one day and the same drum using water solutions, the amount of wood required should be, approximately, 1 cwt. to 1¼ cwt. For similar oil treatments, the quantity would be considerably less. With firewood estimated at 6s. per ton for collection and cartage to the treating site, the cost per day per two 4-hour treatments is about 4d. to 5d.

Labour.—The cost of labour for the treatment of fence posts as outlined above is difficult to estimate. Fence post treatment does not require continuous supervision. Once the solution has been heated, the posts inserted, and the correct treating temperature reached, only occasional firing and adjustment of solution levels is necessary. On a farm, therefore, a man treating posts can be doing other odd jobs at the same time. Also it is possible that treating can be carried out at times when conditions are unsuitable for general farm work. If labour is employed continuously on fence post work, then the size of the treatment plant should be enlarged so that the labour cost per post is low.

11. Estimated Cost of Treated Fence Posts.

The cost of a treated fence post depends primarily on the cost of the untreated post, the cost of preservative and the amount of it absorbed by the post, the output of the plant and labour. In Tables 4 and 5 the estimated costs of treatment of posts of an average butt diameter of 4 inches are given. The times of treatment are based on those in Tables 1 and 2, and it is assumed that there is a total of four drums for treatments.

A study of the tables shows that for treatment with creosote and fuel oil the items making up the cost of treatment are distributed in the order:—Cost of preservative, cost of untreated posts, and labour. Where large numbers of posts are to be treated, the cost of labour per 100 posts can be considerably lowered by increasing the number of treating drums.

In the case of treatment with water-soluble preservatives, the items making up the cost of treatment are distributed in the order:—Cost of untreated posts, labour, and cost of preservatives. Treatment with water-soluble preservatives costs less than with creosote and oil. Offset against the lower cost of treatment, however, is the fact that creosote and oil-treated posts will generally give longer life than posts treated with water-soluble preservatives, the latter materials being liable to be washed out of the wood by rain, drainage water, &c.

Table 4.—Estimated Cost of Treating with Creosote and Fuel Oil 100 Fence Posts, Average Butt Diameter 4 Inches, Adding Freight for 200 Miles to Cost of Chemicals Used, and Using Four Drums for Treatments.

Species.	Average absorption per cubic foot of length treated.	Absorption of preservative per 100 posts.	Time of treatment.	Cost of barked untreated posts.	Cost of preservatives absorbed.	Cost of treated posts excluding labour.*
	lb.	lb.	days.	£ s. d.	£ s. d.	£ s. d.
Brown Mallet ..	7·5	163·5	2	1 0 0	1 7 1	2 7 1
Gimlet	7·0	152·6	2	1 0 0	1 5 3	2 5 3
Goldfield's Redwood	5·0	109	2	1 0 0	0 18 1	1 18 1
Jarrah	6·0	130·8	1½	1 0 0	1 1 8	2 1 8
Marri (Red Gum) ..	7·0	152·6	2	1 0 0	1 5 3	2 5 3
Morrell	9·0	196·2	2	1 0 0	1 12 6	2 12 6
Salmon Gum ..	6·0	130·8	2	1 0 0	1 1 8	2 1 8
Pinus radiata ..	9·0	196·2	1	1 5 0	1 12 6	2 17 6

* Note.—When treatment can be carried out under favorable conditions and only the actual time of working on the treatment is chargeable, the estimated cost of labour at £3 15s. per week, for brown mallet, gimlet, Goldfield's redwood, marri, morrell and salmon gum would be about 18s. per 100 posts, for jarrah about 14s., and *Pinus radiata* 10s. per 100. A small charge for firewood of about 1s. to 1s. 6d. per 100 posts and any minor items should be added to the cost given under "Costs of treated posts".

TABLE 5.—ESTIMATED COST OF TREATING WITH WATER-SOLUBLE PRESERVATIVES 100 FENCE POSTS, AVERAGE BUTT DIAMETER 4 INCHES, ADDING FREIGHT FOR 200 MILES TO COST OF CHEMICALS USED, AND USING FOUR DRUMS FOR TREATMENTS.

Species.	Average absorption of solution per cubic foot of length treated.	Absorption of solution per 100 posts.	Time of treatment.	Cost of barked untreated posts.	Cost of preservatives absorbed.		Cost of treated posts excluding labour.*	
					Sodium fluoride and white arsenic.	Zinc chloride and white arsenic.	Sodium fluoride with white arsenic.	Zinc chloride with white arsenic.
	lb.	lb.	days	£ s. d.	s. d.	s. d.	£ s. d.	£ s. d.
Brown Mallet ..	12	262	1½	1 0 0	6 10	9 3	1 6 10	1 9 3
Gimlet ..	9	196	2	1 0 0	5 1	7 0	1 5 1	1 7 0
Goldfield's Redwood	8·5	185	2	1 0 0	4 10	6 7	1 4 10	1 6 7
Jarrah ..	11	240	1½	1 0 0	6 3	8 6	1 6 3	1 8 6
Marri (Red Gum)	13	283	1	1 0 0	7 4	10 0	1 7 4	1 10 0
Morrell ..	12	262	2	1 0 0	6 10	9 3	1 6 10	1 9 3
Salmon Gum ..	10	218	2	1 0 0	5 8	7 9	1 5 8	1 7 9
Pinus radiata ..	11	240	1	1 5 0	6 3	8 6	1 11 3	1 13 6
Boree	7	153	2	1 0 0	4 0	5 5	1 4 0	1 5 5

* NOTE.—When treatment can be carried out under favorable conditions and only the actual time of working on the treatment is chargeable, the estimated cost of labour at £3 15s. per week for gimlet, Goldfield's redwood, morrell, salmon gum and boree would be about 18s. per 100 posts, for mallet and jarrah about 14s. per 100 posts, and marri and *Pinus radiata* about 10s. per 100 posts. A small charge for firewood of about 1s. to 1s. 6d. per 100 posts, a charge for carting water to the treating plant, and any minor items should be added to the cost given under "Costs of treated posts".

However, in the Eastern wheat belt, in rainfall areas below about 18 inches per annum, the factor of leaching becomes less important and the use of water-soluble preservatives is recommended.

The estimates given in Tables 4 and 5 are a guide only, and in estimating his own costs a farmer should make allowance for the actual cost to him of preservatives, untreated fence posts, and labour. If only a small number of posts are being treated, the total or a large proportion of the cost of the treating plant should be debited against the cost of the treatment. At the conclusion of the treatment, there will remain on hand quantities of preservative solutions, which will be found to be of considerable value for brush treating shed posts, gates, and other farm structures.

12. Probable Life of Treated Fence Posts.

No data are available regarding the life of treated fence posts for the species of timber available for treatment in Western Australia. Experience with preserved fence posts in other countries, however, shows that properly-creosoted posts will give a life of at least 20 to 25 years. In dry localities, posts treated with water soluble preservatives should give a life closely approximating this.

In conjunction with the Western Australian Forests Department, about 1,800 fence posts were treated with preservatives as set out in this publication. These posts have been installed in fence lines in three different localities in Western Australia, viz., Ghooli (near Southern Cross), Wickepin, and Pemberton. Frequent inspections of these lines will be made, and when the information is available, details of results being obtained will be widely published in agricultural papers.

13. Economy of Treatment.

Although it is possible to increase the life of timber by preservative treatment, it is not economical to do so unless the cost of treatment is more than repaid by the increase in the life of the post. The cost for setting an untreated post is the same as for a treated post. If a treated post will last twice as long as an untreated one, then to the increased life of the treated post must also be added the cost that would have to be borne if the untreated post was removed and a new one put in its place. The best method of comparison therefore is to determine the annual service charge (cost per year of life) as distributed over the length of life of the post, assuming a constant charge for setting, compound interest at, say, 5 per cent. per annum, and no value for the eventually destroyed fence post. The costs per year of life of a post costing one shilling in place are given in Table 6.

TABLE 6.—COSTS PER YEAR OF LIFE OF POSTS COSTING 1S. IN PLACE. COMPOUND INTEREST AT 5 PER CENT.

Life in Years.	Annual Service Charge.	Life in Years.	Annual Service Charge.	Life in Years.	Annual Service Charge.
	s.		s.		s.
1	1·050	11	0·121	21	0·078
2	0·538	12	0·113	22	0·076
3	0·367	13	0·107	23	0·074
4	0·282	14	0·101	24	0·073
5	0·231	15	0·097	25	0·071
6	0·197	16	0·092	26	0·070
7	0·173	17	0·089	27	0·069
8	0·155	18	0·086	28	0·076
9	0·141	19	0·083	29	0·066
10	0·130	20	0·080	30	0·065

From Table 6, the cost per year of life for a post which cost 1s. 6d. to set, and which lasted ten years, would be 0.130 multiplied by 1½ equals 0.195 shillings, or about 2⅓d.

The following figures give an indication of the method for determining the economical value of treatment. The details of working are given in Appendix 4.

1. (*a*) For an untreated salmon gum post costing 2d. to cut and 1s. to set, and lasting seven years, the cost per year of life would be 0.202 shillings, or about 2½d.

(*b*) For a salmon gum post treated with creosote and fuel oil at a cost of 8d., plus 1s. to set, and lasting 20 years, the cost per year of life would be 0.133 shillings, or about 1½d.

(*c*) For a salmon gum post treated with sodium fluoride and white arsenic at a cost of 6d., plus 1s., to set, and lasting fifteen years, the cost per year of life would be 0.145 shillings, or about 1¾d.

The above figures show that both creosote with oil, and sodium fluoride with white arsenic treatments would result in a considerable saving over the use of untreated posts. For one post, this does not seem large, but if the results are considered for 1,000 posts the saving would be £3 9s. per year when using creosote with fuel oil, and £2 15s. per year when using sodium fluoride with white arsenic.

2. If a durable post costing 1s. on the farm, plus 1s. to set, lasts 30 years, the annual service charge would be 0.130 shillings. Creosote and oil-treated salmon gum posts, lasting 20 years, would have a cost per year of life of 0.133 shillings (see above). The difference is very small, and on account of the lower actual immediate outlay in money (£5 per 100 for naturally durable posts as against about £2 5s. per 100 for creosote and oil-treated salmon gum) the ordinary farmer would probably consider the treated salmon gum post as being the better for his purpose.

By estimating his own costs of treatment, by determining the probable cost per year of life on his posts, and by considering his initial outlay, a farmer can make his own decision on the advisability of treating and on the type of treatment.

14. Conclusions.

The preservative treatment of fence posts means, in a large number of cases, a saving in first cost together with, in many cases, a reduced cost per year of life. It also makes available for use large quantities of timber which would otherwise be destroyed in clearing operations.

Three different types of preservatives are described for use with the open tank process and the choice of any one will depend on the cost, the availability of supplies, the location of use, and the estimated life or annual service charge. Creosote with fuel oils is better for use in wetter localities and treatment with this type of preservative is generally easier and simpler than with water-soluble preservatives. Either of the two types of water soluble-preservatives, i.e., sodium fluoride with white arsenic or zinc chloride with white arsenic will give good service in drier localities and the choice of these latter preservatives is a question of price and availability.

If information on source of supplies is required, inquiries should be addressed to the Conservator of Forests, Forests Department, Perth, or the Chief, Division of Forest Products, 314 Albert-street, East Melbourne.

The practice of preservation can likewise be extended to farm timbers other than fence posts, and the Division of Forest Products will gladly advise and assist farmers or other users of timber.

The Division would be grateful if those who have adopted the methods of treatment of this publication would forward details of the quantity and kind of posts treated, and of the preservatives used. This information will be of value in future years as a record of the advantages to be gained by preservative treatment.

APPENDIX 1.

Creosote Oil.

In this appendix, full details are given regarding the quality of creosote oil suitable for fence post treatments. If a user of oil is in doubt as to whether a grade of oil offered for sale is suitable he should state on his order that it must comply with the specification given below. It should not be necessary to do more than refer to this publication which will be forwarded to all known creosote producers in Australia.

In England, Europe, and the United States of America, creosote oils mostly used for wood preservation are horizontal retort oils and any such creosote oil conforming to the British Engineering Standards Association specification No. 144, 1921, or grade 1 and 2 of the American Wood Preservers' Association, is satisfactory for fence posts.

The bulk of Australian creosotes are produced from vertical retorts and they differ considerably from the horizontal retort oils. An investigation is now being undertaken to determine suitable specifications for these oils. Pending the completion of this, a tentative specification complied from the results of the investigation to date, together with information collected from England, the United States of America, and New Zealand is suggested for use. This tentative specification is, of course, subject to modification after completion of the work. Vertical retort creosotes bought according to this specification should give complete satisfaction as fence post preservatives.

Tentative Specification for Australian Creosote Oils for Fence Post Preservation.

1. The oil shall be a distillate of coal tar and be free of any admixture of petroleum or similar oils. (In the case of ready-prepared creosote with oil mixtures the creosote used shall conform to the specification, and be in the proportion of at least 2 parts of creosote to 1 part of petroleum oil).

2. The specific gravity of the oil at 38°C. compared with water at 15.5°C. shall be not less than 0.94.

3. The oil shall not contain more than 3 per cent. of water.

4. The oil shall not contain more than 0.5 per cent. of matter insoluble in benzol.

5. The distillate based on water-free oil shall be within the following limits:—

    Up to 210°C. not more than 10 per cent.

    Up to 235°C. not more than 35 per cent.

    Up to 315°C. not more than 85 per cent.

6. The residue above 355°C. if it exceeds 5 per cent. shall have a float test of not more than 50 seconds at 70°C.

7. The amount of tar acids shall be not less than 5 per cent. by volume. There shall be no upper limit to the amount of tar acids.

8. The foregoing tests shall be made in accordance with the standard methods of the American Wood Preservers' Association. (Details of these methods will be supplied on application).

APPENDIX 2.

Method of Controlling the Strength of Water Solutions.

It is very desirable that the strength of the treating solutions should be controlled. This can easily and conveniently be done by the use of a hydrometer, which is an instrument for determining the density or strength of solutions. A type recommended for use with the solutions of sodium fluoride with white arsenic and zinc chloride with white arsenic for the open tank process is one marked from 1,000 to 1,060, costing about 3s. 6d. to 4s. 6d. In use, it is simply placed in a long glass or tin of solution, and the point at which the liquid and the scale-marking coincide is noted. It will be found that the solution will be raised slightly around the glass stem of the hydrometer. The reading should be taken at the top of the raised surface against the hydrometer stem.

When using the hydrometer, the following simple precautions should be taken:—

1. The stem should be dry when it is used and it should be carefully inserted into the liquid so that the stem is not wet excessively.
2. The hydrometer should float freely in the solution and should not be in contact with the sides of the vessel when the reading is taken.
3. After use the hydrometer should be rinsed in clean water and dried.

As explained on page 24 the strength of the treating solutions can be roughly regulated by ensuring that during the boiling period, *water* is added to make up loss by evaporation, and during the cooling period, *solution* to make up for that absorbed by the posts. It is desirable that a closer control of the strength than is possible by this method is used. This can be very simply and conveniently done by using a hydrometer and a Fahrenheit thermometer.

When the fresh solution is prepared, a sample should be removed in a convenient vessel, allowed to cool, and the hydrometer reading taken together with the temperature. Whenever the strength of the treating solution is again determined, care should be taken that the temperature is not more than 5° Fahrenheit above or below that of the temperature of the fresh solution, as a larger difference in temperature affects the reading on the hydrometer. The strength of the fresh solution should be carefully recorded, as it is to be used for comparison with the treating solutions in use.

The strength of the fresh zinc chloride and white arsenic solution should be about 1050 at 60°F., 1049 at 70°F., and 1047 at 80°F., while the fresh sodium fluoride and white arsenic solution should be about 1053 at 60°F., 1051 at 70°F., and 1050 at 80°F. Commercial hydrometers vary somewhat, and it may be found that the strengths of the fresh solutions will differ from the figures given above by one to three points. Provided however, that the reading is carefully taken, the actual figure obtained does not matter.

If the treating solution is becoming weaker, it will be found that the hydrometer reading will be less than that for the fresh solution. For every point difference, one-half gallon of solution should be added during the boiling period to the treating drum (containing 25 gallons) to make up for some of the evaporation. For example, if the strength of the fresh solution at 70°F. is found to be 1049, and the strength of the solution being tested is 1043 at the same temperature, then the difference in the hydrometer readings is 6. Therefore, in order to increase the strength of the treating solution to normal, 6 multiplied by one-half, i..e., 3 gallons of solution, should be added to the 25 gallons of solution in the treating drum during the boiling period. The same method applies, whether the zinc chloride with white arsenic or sodium fluoride with white arsenic solutions are used.

If the strength of the treating solution becomes greater than that of the fresh solution it can be corrected by adding water directly to the treating drum. If the level in the treating drum is correct, a better way is to remove solution and replace it by water. For each point of the hydrometer reading greater than the recorded reading of the fresh solution, remove half-a-gallon of solution and replace it by half-a-gallon of water.

A kerosene or petrol tin holds 4 gallons of water or solution, and is a convenient measure for use. If the height of the tin is divided into eight equal parts, and these are clearly marked on the outside, each mark will represent, approximately, half-a-gallon of solution.

Tests of the strength of the water treating solutions should be made, if treatment is continuous, at least twice a week. More frequent determinations will give closer control of the strength of the solutions, but, if care is taken to follow the directions given, these are not thought to be necessary.

APPENDIX 3.

Precautions when using White Arsenic.

White arsenic is a poison, and care should be taken while using it. On no account should the powder or the solution be kept near food of any description. The precaution of thoroughly washing the hands after handling the solution or treated posts before handling food will prevent any trouble. If sores, open cuts, or abrasions are on the operator's hands, they should be kept well bandaged and out of contact with solution as festering is likely to occur.

If by accident the white arsenic solution or powder is swallowed, vomiting should be brought about by taking a glass full of luke warm water containing one tablespoon of salt or a dessert spoonful of mustard, or by tickling the throat with a feather. Drinks of milk, raw eggs and milk, olive oil, or strong tea should be taken afterwards. If necessary medical advice should be obtained.

APPENDIX 4.

Economy of Treatment—Details of Calculations.

The figures in Table 6, giving the cost per year of life of posts costing 1s. in place, compound interest at 5 per cent. were obtained from the formula—

$$\text{Cost per year of life} = \frac{CR\,(1 + R)^n}{(1 + R)^n - 1}$$

where C = final cost of post in place,
R = rate of interest (5 per cent. = 0.05),
n = life of posts in years.

By using this formula, the figures in Table 6 can be extended beyond the period of 30 years if so desired.

Details of working—

1. (*a*)	Cost of cutting salmon gum post	0 2d.
	Cost of setting	1 0
	Total cost of untreated post in fence	1 2
	Estimated life of untreated post	7 years.

Cost per year of life = 0.173 (from Table 6) multiplied by 1⅙ shillings.
= 0.202 shillings, or about 2½d.

(*b*)	Cost of cutting, seasoning, and treating salmon gum post with creosote and fuel oil	0 8d.
	Cost of setting	1 0
	Total cost of treated post in fence	1 8
	Estimated life of treated post	20 years.

Cost per year of life = 0.080 (from Table 6) multiplied by 1⅔ shillings.
= 0.133 shillings, or about 1½d.

(*c*)	Cost of cutting, seasoning, and treating salmon gum post with sodium fluoride and white arsenic ..	0 6d.
	Cost of setting	1 0
	Total cost of treated post in fence	1 6

Cost per year of life = 0.097 (from Table 6) multiplied by 1½ shillings.
= 0.145 shillings, or about 1¾d.

2.	Cost of durable post	1 0
	Cost of setting	1 0
	Total cost of durable post in fence	2 0
	Estimated life of durable post	30 years.

Cost per year of life = 0.065 (from Table 6) multiplied by 2 shillings.
= 0.130 shillings or about 1½d.

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COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

Termites (White Ants) in South-eastern Australia

A simple Method of Identification and a Discussion of their Damage in Timber and Forest Trees

By

GERALD F. HILL

MELBOURNE, 1932

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CONTENTS.

FOREWORD.

The paper entitled "Termites (White-Ants) in South-eastern Australia," by Mr. G. F. Hill, Senior Entomologist in charge of the Section of Forest Insect Pests in the Division of Economic Entomology, C.S.I.R., is written with the principal object of providing a reliable guide to foresters and all others interested in our native Eucalyptus trees in South-eastern Australia, on the subject of the damage caused by termites or white-ants. It is hoped that all such workers will be enabled, by means of this paper, to identify the commoner species of termites which they may find damaging timber. A further objective of the paper is to interest a large number of forestry workers in these insects, in the hope that they will collect them more frequently and send in their specimens to Mr. Hill for identification. All such consignments should, as far as possible, contain winged forms and soldiers as well as workers, since it is extremely difficult, and sometimes quite impossible, to name a termite correctly unless the complete series of castes is available.

The paper is written in simple language, and such scientific or technical terms as are unavoidably used have been carefully defined in the glossary at the end of the paper. Two sets of keys are given, one for the determination of the four distinct families of termites, and the other for the separation of the different species dealt with. The numerous figures provided should prove sufficient for the non-expert to recognize the different species with which he is likely to meet in carrying on forestry work in South-eastern Australia.

R. J. TILLYARD,
Chief, Division of Economic Entomology.

Termites (White Ants) in South-eastern Australia.

A simple Method of Identification and a Discussion of their Damage in Timber and Forest Trees.

1. Introduction.

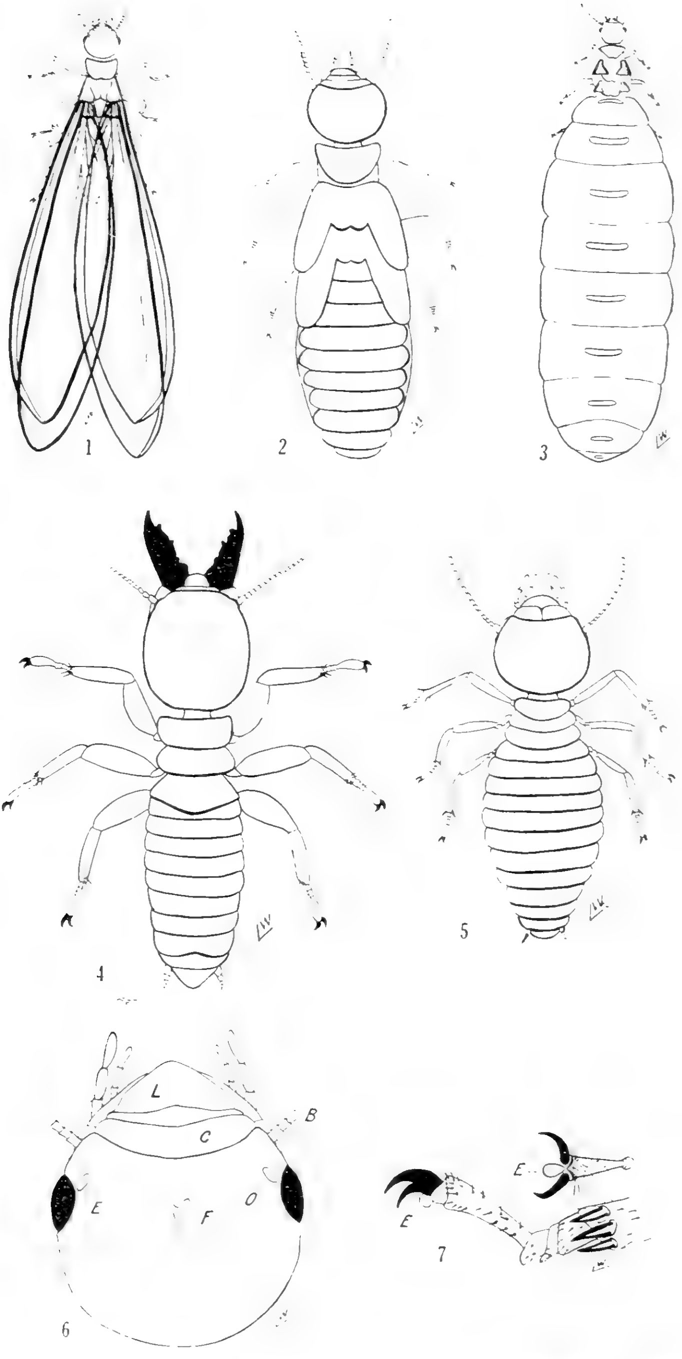
The urgent necessity for conserving our rapidly diminishing timber resources has directed attention to the enormous economic losses resulting from the ravages of insect pests and fungus diseases. Recent publications by the Council for Scientific and Industrial Research indicate the extent of these losses and the steps which are being taken to minimize them. Divisions of the Council are carrying out researches on the systematics, biology, and distribution of termites, and on methods of wood preservation, with the object of devising means of minimizing losses in timber, forest trees, &c., and of determining and standardizing satisfactory methods of wood preservation. Other Commonwealth and State organizations are investigating other problems with the same ultimate object in view.

That termites play a part which entitles them to rank amongst the major causes of destruction of timber structures and commercial forest trees is evident.

The object of this paper is to give a brief outline of the classification and known habits of those species of termites which are most likely to come under the notice of forest officers and others in south-eastern Australia who, though interested in these insects, have neither the time nor the opportunities for detailed studies, such as are now, more than ever, engaging the attention of entomologists throughout the termite-infested regions of the world.

Termites differ from most other groups of insects in having several very distinct forms or castes, and, in some instances, in having more than one form of the same caste. The castes generally found in a colony are—(1) winged males and females, (2) soldiers, and (3) workers.

The winged insects (alates or imagos) are present in the colony during the spring, summer, or autumn, according to the species, and leave the parent nest once and for good for the sole purpose of mating and founding new colonies. This colonizing flight usually takes place on a dull day during or following a fall of rain, when thousands of individuals flutter from the nest or mound in a short erratic flight. The wings are then broken off at a transverse suture near the base of the wing, leaving a short wing-stump or scale, which remains throughout the life of the insect. In this condition, the de-alated pairs seek shelter in branch stubs, crevices in wood, or under logs and other debris, where they mate and found a new colony, of which they become the king and queen. The earlier stages (nymphs) of the winged forms are readily distinguished from the larvae and workers by the possession of short wing-buds; all are more or less whitish in colour.



Figs. 1–7.—1. Winged form or imago. 2. Nymph (immature stage of the winged form). 3. Queen. 4. Soldier. 5. Worker. 6. Head of winged form: *B* basal segments of antennae; *C* posterior part of clypeus; *E* eye; *F* fontanelle; *L* labrum; *O* ocellus. 7. Claws, showing empodium (*E*) seen from above and from the side.

The soldiers, which are sterile and generally blind, are present in the colony throughout the year. They direct the other members of the community, and protect them from the attacks of marauding ants and other enemies; but, since they are unable to feed themselves, they are dependent upon the workers for their existence. The soldiers of all species are distinguished from the other castes by their large yellow or reddish heads and long powerful jaws, or by the peculiar form of the head (in *Eutermes*).

The workers are distinguished by their rounded and usually pale-coloured heads, concealed jaws, and whitish soft bodies. Their functions are to gather food, feed the other members of the colony, tend the eggs and young, build the nest, and act as scavengers. Once the colony is founded, they become indispensable members of the community, and they alone cause damage to timber. In one group (*Calotermitidae*) there are no true workers, the functions of this caste being performed by the immature stages (larvae and nymphs) of the winged form.

The winged forms are important, and sometimes indispensable for the purpose of specific identification, but they are not often available for examination, and when available are not always readily classified; the soldiers, however, which are invariably present in the colony, generally possess good specific characters, and are often the most suitable upon which to base field identifications.

Termites generally live on cellulose, which is the main constituent of wood, hence the destruction of trees and seasoned timber. In addition, they may be found eating leather, sugar, sugar-cane, horn, bone, leaves, grass, seeds, &c., and they will bore through cement of poor quality and sheet lead in order to gain access to more palatable material or to moisture. It is interesting to note that they cannot digest wood, and are dependent for their existence on protozoa which are capable of doing so. Such organisms live normally in the gut of all wood-eating species, and without them termites cannot live for more than a few weeks, even in the presence of an abundant supply of wood.

Termites are classified into four families, which can be distinguished by the following key:—

2. Key to the Families of Termites.

A. Tarsi 5-jointed in all castes.
Hindwing with large anal lobe.

Family: *Mastotermitidae*
(not found in Southern Australia).

B. Tarsi 4-jointed in all castes.
Hindwing without anal lobe.

(*a*) Fontanelle wanting in all castes.
Wing-membrane reticulated.
Stump of forewing distinctly larger than that of hindwing.
Empodium present except in *Porotermes.*
Soldier with pronotum generally flat, sutures of head usually distinct, eyes present.

Calotermitidae.

(*b*) Fontanelle present in all castes.

Wing-membrane often reticulated.

Stump of forewing distinctly larger than that of hind-wing.

Empodium always absent.

Soldier with pronotum flat and without well-marked anterior lobes; eyes absent.

Worker with pronotum flat except in *Rhinotermes*.

Rhinotermitidae.

(*c*) Fontanelle present in all castes.

Wing-membrane never strongly reticulated.

Stump of forewing small.

Empodium always absent.

Soldier and worker with pronotum always saddle-shaped.

Termitidae.

Ten species of termites, representing three families and six genera, are found commonly in growing trees and timber structures in south-eastern Australia; they are as follows:—

Family: CALOTERMITIDAE.

1. *Porotermes adamsoni* (Froggatt).
2. *Calotermes insularis* (White).
3. *Calotermes iridipennis* Froggatt.
4. *Calotermes rufinotum* Hill.
5. *Calotermes oldfieldi*, var. *chryseus* Hill.

Family: RHINOTERMITIDAE.

6. *Rhinotermes intermedius* Brauer.
7. *Coptotermes lacteus* (Froggatt).
8. *Coptotermes flavus* Hill.
9. *Heterotermes ferox* (Froggatt).

Family: TERMITIDAE.

10. *Eutermes exitiosus* Hill.

These ten species may be recognized in the alate and soldier castes with the aid of the succeeding descriptions and figures,* which are preceded by brief accounts of their distribution and habits, as far as they are known.

Only Nos. 7 and 10 build mounds; Nos. 1 to 5 live in rambling galleries in trees, whilst No. 9, and probably No. 6 also, live in nests in the soil. No. 8 probably nests only near ground-level in the butts of trees, from which it works upwards through the trunk and main branches.

The above list does not include several species that are believed to be of little or no economic importance, or which cannot be readily distinguished from some of the commoner and more destructive species.

* Some kindly prepared by Mrs. L. Willings.

In the detailed descriptions following the key, the measurements are given in millimetres, followed (in parentheses) by their approximate equivalents in 1-16 inches. The few structural features referred to are illustrated in Figures 6 and 7, and are further explained in the glossary at the end of the paper.

The key presented below is intended to serve only as a ready means of indicating with a fair degree of accuracy the identity of the various species referred to in this paper; in all cases identifications made from it should be checked with the descriptions.

3. Key for the Identification of the Termites Listed on Page 10.

A. Mound Builders (sometimes in trees).

(*a*) Mound 3 to 7 feet high, comprising a dense clayey wall from 1 to 2 feet thick loosely enveloping a woody interior of much darker colour (see Fig. (*a*), Plate 1)*. Soldier small (about 1/8 inch long), head yellow, markedly narrowed anteriorly; mandibles long, slender, sabre-shaped; in life a globule of milky white secretion on front of head. Winged form of medium size (about 9-16 inch long), dark brown, with smoky wings.

Coptotermes lacteus (see *C. flavus* below).

(*b*) Mound from 18 inches—2 feet high, comprising a thin earthy crust hardly separable from the cellular earthy and woody interior (see Fig. (*b*), Plate 1).

Soldier small (about 1/8 inch long), head dark brown, pear-shaped, produced into long tapered snout, mandibles rudimentary; pronotum very small, saddle-shaped. Winged form of medium size (about 5/8 inch long), with dark head and yellowish-brown body, wings light brown.

Eutermes exitiosus.

B. Soil Dwellers (never in trees; commonly under logs and in houses).

(*a*) Soldier small (about 1/4 inch long), with pale yellow, long, parallel-sided head, and sabre-like mandibles; labrum (upper lip) long, pointed at tip. Winged form small (about 7-16 inch long), dark brown with light smoky wings; head widened towards the front; eyes very small.

Heterotermes ferox.

(*b*) Soldiers small, of two sizes (about 1/4 and 3-16 inches long respectively); head yellow, relatively short and wide; mandibles strongly toothed, labrum large, wide at top. Winged form of medium size (about 5/8 inch long), yellow, with glassy wings; head large, rounded; eyes very large.

Rhinotermes intermedius.

C. Tree Dwellers (never in mounds or soil).

1. *Porotermes adamsoni:* Soldier large (about 1/2 inch long), head wide and markedly flattened; mandibles large,

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* On page 28.

strongly toothed, curved downward; pronotum narrower than head. Winged form of medium size (about 9-16 inch long), tawny; pronotum narrower than head; eyes moderately large.

2. *Coptotermes flavus:* Soldier indistinguishable in the field from *C. lacteus.* Winged form small (about 7-16 inch long), light brown, with light smoky wings. (See *Coptotermes lacteus* above).

3. *Calotermes:* Soldier small to large, mandibles very long or short, bent upward, never downward, always with large teeth; head never markedly flattened. Winged form light yellow or dark brown; pronotum very large, wider than head.

(*a*) Soldier with long mandibles.

(*aa*) Soldier large (about ½ inch long); mandibles stout; 3rd segment of antenna small, not much larger than 2nd and 4th. Winged form large (about 1 inch long), light yellow; eyes large.

Calotermes insularis.

(*bb*) Soldier of medium size (about ⅜ inch long); mandibles slender; 3rd segment of antenna very large, much larger than 2nd and 4th, club-shaped. Winged form of medium size (about ½ inch long), light yellow; eyes of medium size.

Calotermes oldfieldi var. *chryseus.*

(*b*) Soldiers with short mandibles.

(*aa*) Soldier of medium size (about ⅜ inch long). Winged form small (about 7-16 inch long), dark brown; head and pronotum dark brown.

Calotermes iridipennis.

(*bb*) Soldier small (about ¼ inch long). Winged form small (about ⅜ inch long), dark brown; head and pronotum orange.

Calotermes rufinotum.

4. Porotermes adamsoni.

(Fig. 8 (a—d).)

Distribution.—New South Wales (eastern districts as far north as Uralla); Federal Capital Territory; Victoria (southern and eastern districts), and Tasmania.

Host Plants.—Eucalyptus gigantea, E. fastigata, E. viminalis, E. rubida, E. radiata, E. stellulata, E. Dalrympleana, E. macrorrhyncha, E. polyanthemos, E. coriacea, E. maculosa, E. regnans,* and *E. obliqua.*

This species, like the others listed under the family Calotermitidae, does not build mounds (termitaria) but lives in large slit-like galleries tunnelled in wood. Hitherto it has been regarded as of little or no economic importance owing to the fact that it is generally found in dry

* The known host plants are listed for each species, but it is probable that other trees are attacked.

timber (firewood) or in rotten logs and stumps. Recent investigations however, have shown it to be one of the most, if not the most, destructive species to growing commercial forest trees, particularly in the Federal Capital Territory, where *Eucalyptus fastigata*, *E. gigantea*, *E. viminalis* and *E. Dalrympleana* appear to be very susceptible. It is known also to attack *E. regnans*, *E. obliqua*, and *Pinus radiata* in Victoria. The commonly accepted statement that termites will not attack normally healthy trees is incorrect, since investigations now in progress show conclusively that a dead branch, branch stub, or a scar resulting from a broken limb or superficial fire damage may provide a point of entry for the winged pairs into sound millable timber. It is believed that in all cases contact must be made with dead wood, and that the insects are unable to gain entry through sound living bark. The point of entry may be at or near ground level or may be at any height up to 140 feet, and probably more; in either case, the subsequent destruction of the tree by the progeny of the original reproductive pair appears to be only a matter of time. At what age trees are attacked is not known, but it is certain that primary infection often occurs in mature or nearly mature trees. Little or nothing is known of the maximum age of colonies of termites, but in this, as in other species, the production of supplementary reproductive males and females, a phenomenon of common occurrence, would appear to place no limit to the life of the colony after the death of the original king and queen. The tunnelling of the entire trunk and main branches of a large forest tree may well be a matter of 20 or 30 years of ceaseless energy on the part of such colonies as occur commonly in many apparently healthy trees. Whether the colonies found in rotten logs and stumps originated therein or whether they are the survivors of much larger and older colonies which commenced their existence in a living tree is not known, but the latter would appear to be the more probable.

The condition known as "mud-guts" is found commonly in large trees, the heart of which has been greatly damaged or completely destroyed by *Porotermes*. The ash forest seems to be particularly susceptible to damage, and it frequently happens that as much as 50 per cent. of the standing timber is left in the bush after logging operations. Frequently there is little external evidence of the condition of the tree, but the expert feller can form a very good idea by sounding with the axe. The enormous quantity of matter tightly packed into the space formerly occupied by wood appears to be composed entirely of waste products execreted by the termites over a very long period of years. A similar condition occurs in trees attacked by *Coptotermes*, but with some species at least the matter contains a large proportion of earth or clay.

Porotermes froggatti and *Porotermes grandis*, of Tasmania and Victoria respectively, are very destructive forms; these should possibly be included under *Porotermes adamsoni*.

IMAGO.

Length with wings	14·00–15·00 mm. ($\frac{9}{16}$ — to $\frac{9}{16}$ +)*
Length without wings	7·00– 8·00 mm. ($\frac{1}{4}$ + to $\frac{5}{16}$)
Head, wide	1·66 mm. ($\frac{1}{16}$)
Pronotum, wide	1·48 mm. ($\frac{1}{16}$ —)

* The fractions given in brackets are fractions of an inch. The sign " — " is used to indicate "slightly less," and the sign " + " for "slightly more"; e.g., $\frac{1}{16}$ — to $\frac{1}{16}$ + means slightly less than $\frac{1}{16}$ of an inch to slightly more than $\frac{1}{16}$ of an inch.

Uniform tawny in colour; anterior veins of wing crowded towards the fore-border; the radial sector with many oblique branches to the front margin; median vein not very near the radial sector; eyes rather small; ocelli, fontanelle, and empodium wanting; pronotum wider than long, narrower than head.

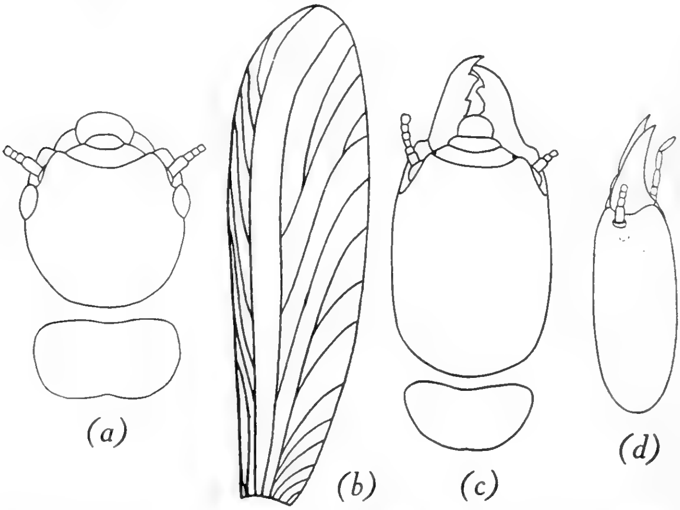


FIG. 8.—*Porotermes adamsoni:* (*a*) Head and pronotum of imago. (*b*) Wing. (*c*) Head and pronotum of soldier seen from above. (*d*) Head and pronotum of soldier seen from the side. (As printed, figure (*d*) should be viewed with the mandibles to the right).

SOLDIER.

Total length	8·75–11·25 m.m ($\frac{5}{16}$ + to $\frac{7}{16}$ +)
Head, with mandibles, long	3·36– 4·64 mm. ($\frac{1}{8}$ + to $\frac{3}{16}$ —)
Head, wide	1·82 –2·50 mm. ($\frac{1}{16}$ + to $\frac{1}{8}$ —)
Pronotum, wide	1·20– 1·82 mm. ($\frac{1}{16}$ — to $\frac{1}{16}$ +)

Head light ferruginous behind, shading to dark tawny towards the front, mandibles black; pronotum light yellowish brown, abdomen paler; head large, variable in shape, but always longer than wide, markedly flattened; mandibles large, strongly toothed and bent downwards; pronotum much wider than long, narrower than head, not bent downwards on the sides; empodium wanting.

5. Calotermes insularis.

(Fig. 9 (a—d).)

Distribution.—New South Wales (eastern districts as far north as Sydney); Federal Capital Territory; Victoria (excepting western and north-western districts); New Zealand (? introduced).

Host Plants.—Eucalyptus regnans, E. botryoides, E. polyanthemos, E. melliodora, E. Bridgesiana, E. elaeophora, E. rubida, E. viminalis, E. macrorrhyncha, E. corymbosa, and *E. acmenioides.*

This is one of the largest Australian species, and one which appears to be responsible for very considerable damage to forest trees, particularly in south-eastern Victoria. It has been found in Victoria in *Eucalyptus botryoides* near Orbost, where it is reported by experienced sleeper- and pole-cutters to be very common in all commercial species, and in *E. regnans* in the vicinity of Monbulk and Marysville. It has been found also at Melton in dead timber. In the Federal Capital Territory it occurs commonly in *E. polyanthemos, E. melliodora, E. Bridgesiana, E. elaeophora, E. rubida,* and *E. viminalis* at elevations below 2,600 feet. It has been taken in *E. corymbosa* near Sydney, and in dead timber in several other localities. There are several records of its occurrence in Australian hardwood in New Zealand, the earliest of which date back to 1853, but, if an introduction, it does not appear to have become established as a serious pest.

As far as is known, attacks on living trees commence in branch stubs and other dead wood above ground level, and are carried upwards and downwards until the greater part of the trunk and main branches is affected.

IMAGO.

Length with wings	22·0 –25·00 mm. ($\frac{7}{8}$ — to 1 —)
Length without wings	10·5– 14·00 mm. ($\frac{7}{16}$ — to $\frac{9}{16}$
Head, wide	2·00 mm. ($\frac{1}{16}$ +)
Pronotum, wide	2·36 mm. ($\frac{1}{16}$ +)

Head, thorax, and abdomen tawny, paler beneath, clypeus pale straw, wings hyaline, veins brown, crowded towards the anterior margin, numerous short oblique veins from the radial sector to the fore-border of wings, median vein close and parallel to radial sector; ocelli present: eyes very large, black; fontanelle wanting; empodium present, pronotum very large, much wider than long, much wider than head, strongly arched (bent downwards on the sides).

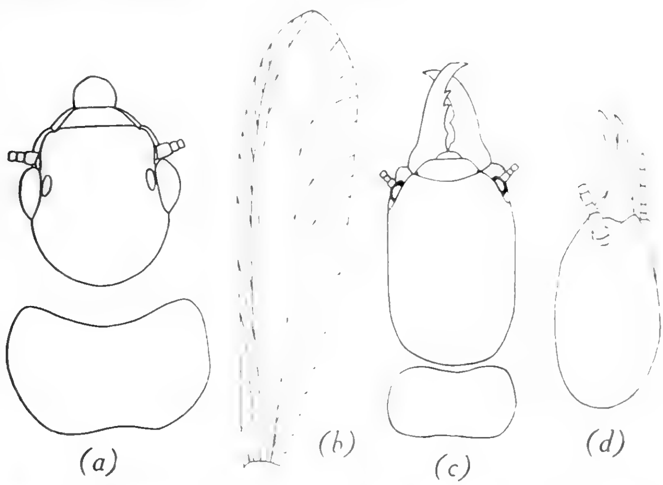


FIG. 9.—*Calotermes insularis*: (*a*) Head and pronotum of imago. (*b*) Wing. (*c*) Head and pronotum of soldier seen from above. (*d*) Head and pronotum of soldier seen from the side. (As printed, figure (*d*) should be viewed with the mandibles to the right.)

SOLDIER.

Total length	12·00–14·75 mm.($\frac{7}{16}$ + to $\frac{9}{16}$ +)
Head, with mandibles, long	6·50– 7·00 mm.($\frac{1}{4}$ +)
Head, wide	3 00– 3·80 mm. ($\frac{1}{8}$ — to $\frac{1}{8}$ +)
Pronotum, wide	3·48 mm. ($\frac{1}{8}$ +)

Head orange-rufous, mandibles black, pronotum yellow abdomen yellowish; head long, much longer than wide, moderately deep, more or less parallel on the sides; mandibles long, stout, strongly toothed, and bent upwards; eyes rudimentary, pronotum much wider than long; antennae long, the third joint darker than others.

6. Calotermes iridipennis.

(Fig. 10 (a—c).)

Distribution.—New South Wales (eastern districts as far north as Sydney); Victoria: south-eastern districts.

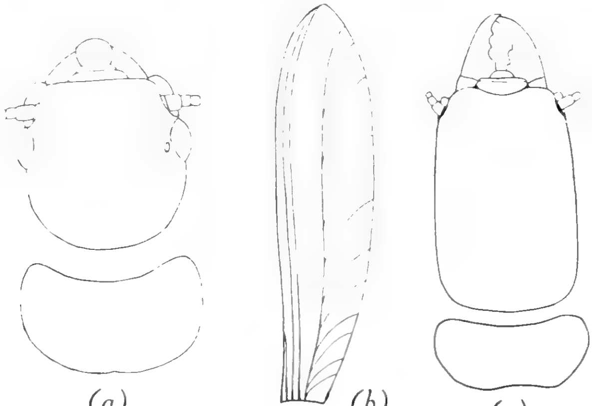
Host Plants.—*Eucalyptus* spp. (unidentified), *Pyrus pashia* (introduced), *Acacia flexuosa* (introduced from Western Australia).

The habits of this species appear to be very similar to those of *C. rufinotum*. It attacks several species of *Eucalyptus* and is stated to be an increasingly important pest in the Botanic Gardens, Melbourne.

IMAGO.

Length, with wings	11·00 mm. ($\frac{7}{16}$)
Length, without wings	7·00 mm. ($\frac{1}{4}$ +)
Head, wide	1·45 mm. ($\frac{1}{16}$ —)
Pronotum, wide	1·42 mm. ($\frac{1}{16}$ —)

Head and body very dark brown, wings light brown, iridescent, densely covered with minute brown dots, the radial sector without oblique branches to the foreborder of the wing, the media close and parallel to radial sector. The uniform dark colour, iridescent wings, and venation are distinguishing features.



(a) (b) (c)

FIG. 10.—*Calotermes iridipennis:* (*a*) Head and pronotum of imago. (*b*) Wing. (*c*) Head and pronotum of soldier.

SOLDIER.

Total length	9·00–10·00 mm. ($\frac{3}{8}$ — to $\frac{3}{8}$ +)
Head, with mandibles, long	3·15– 4·10 mm. ($\frac{1}{8}$ to $\frac{3}{16}$ —)
Head, wide	1·48– 1·76 mm. ($\frac{1}{16}$ — to $\frac{1}{16}$ +)
Pronotum, wide	1·53– 1·88 mm. ($\frac{1}{16}$ — to $\frac{1}{16}$ +)

Head orange-rufous, mandibles black, thorax and abdomen light brownish; head long and narrow, cylindrical; mandibles black, strongly toothed.

7. Calotermes rufinotum.

(Fig. 11 (a—c).)

Distribution.—Federal Capital Territory: various localities at elevations up to 4,100 feet; Victoria: south-eastern districts.

Host Plants.—*Eucalyptus polyanthemos*, *E. radiata*, *E. dives*, *E. coriacea*, *E. fastigata*, *E. gigantea*, *E. maculosa*, *E. viminalis*, *E. Sieberiana*, and others (unidentified).

This species has been found frequently in branch stubs at heights varying from ground level upwards to 140 feet. In many other instances the attack appeared to have originated at a fire scar or other surface injury. In the vicinity of Eden, New South Wales, several living and dead *Eucalyptus Sieberiana* were found to be very badly damaged by this species. The alate form occurs in December.

IMAGO.

Length, with wings	9·00 - 9·50 mm. ($\frac{3}{8}$ —)
Length, without wings	4·50 mm. ($\frac{3}{16}$ —)
Head, wide	1·12 mm. ($\frac{1}{16}$ —)
Pronotum, wide	1·22 mm. ($\frac{1}{16}$ —)

Head and pronotum orange, remainder of thorax and abdomen very dark brown, nearly black; wings smoky, veins darker and crowded towards the fore border, the radial sector with many oblique branches.

The colour of the head and thorax is very characteristic of this species.

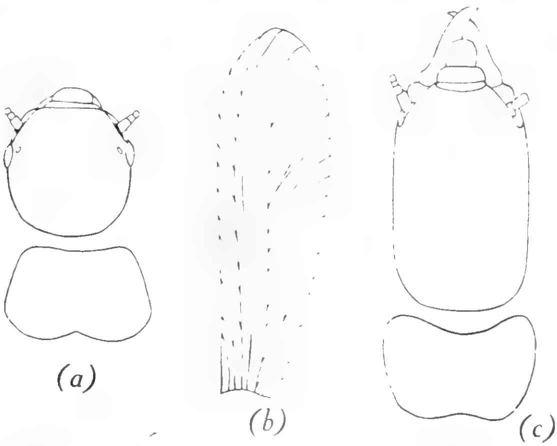


FIG. 11.—*Calotermes rufinotum*: (*a*) Head and pronotum of imago. (*b*) Wing. (*c*) Head and pronotum of soldier.

SOLDIER.

Total length	6·50 mm. ($\frac{1}{4}$ +)
Head, with mandibles, long	2·20 mm. ($\frac{1}{16}$ +)
Head, wide	1·22 mm. ($\frac{1}{16}$ —)
Pronotum, wide	1·13 mm. ($\frac{1}{16}$ —)

Head orange-rufous, mandibles black, thorax and abdomen light brownish-yellow; head long and narrow, cylindrical; mandibles short, stout, and strongly toothed.

8. Calotermes oldfieldi var. chryseus.

(Fig. 12 (a—c).)

Distribution.—New South Wales (eastern districts as far north as Sydney); Federal Capital Territory: various localities at elevations of from 2,300 to 4,000 feet.

Host Plants.—Eucalyptus fastigata, E. gigantea, E. micrantha, E. melliodora, E. Bridgesiana, E. polyanthemos, E. macrorrhyncha, E. elaeophora, and E. Sieberiana.

This species has been found fairly commonly in the Federal Capital Territory in branch stubs, and the truewood, and especially the heart, of living trees, as well as in dead timber, at heights of from a few inches to 140 feet from the ground. The association with other species of *Calotermes* (*C. insularis, C. rufinotum,* &c.) of an isolated soldier or de-alated imago has been noted on several occasions; they live normally, however, in small to moderately large colonies of their own kind. The alate form has been taken from November to February. Like *C. insularis,* it is a night-flying species.

IMAGO.

Length, with wings	12·50–15·50 mm. ($\frac{1}{2}$ to $\frac{9}{16}$ +)
Length, without wings	7·00– 9·50 mm. ($\frac{1}{8}$ + to $\frac{3}{8}$)
Head, wide	1·18– 1·29 mm. ($\frac{1}{16}$ —)
Pronotum, wide	1·40– 1·80 mm. ($\frac{1}{16}$ — to $\frac{1}{16}$ +)

Uniform ochraceous to tawny in colour, wings hyaline, anteriormost veins light brown, the others indistinct; head small, narrowed anteriorly; eyes rather small; ocelli large, in contact with the eyes; pronotum very large, arched, much wider than head, concave in front, rounded on the sides; scales of the forewings very large; legs short and rather stout. Readily distinguished from *Calotermes insularis* by its much smaller size and wing venation, and from *Rhinotermes intermedius* by its smaller head and eyes, much wider pronotum, and wing venation.

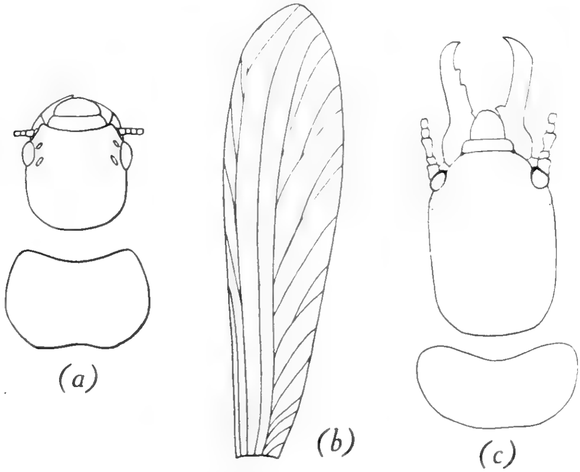


FIG. 12.—*Calotermes oldfieldi,* var. *chryseus:* (*a*) Head and pronotum of imago. (*b*) Wing. (*c*) Head and pronotum of soldier.

SOLDIER.

Total length	6·50– 8·00 mm. ($\frac{1}{4}$ + to $\frac{3}{8}$)
Head, with mandibles, long	2·77 3·80 mm. ($\frac{1}{8}$ — to $\frac{1}{8}$ +)
Head, wide	1·22– 1·48 mm. ($\frac{1}{16}$ —)
Pronotum, wide	0·55– 1·11 mm. ($\frac{1}{16}$ —)

Head ochraceous to ferruginous, base of mandibles ferruginous, the remainder black; head very long and slender, nearly parallel on the sides; jaws very long and slender, nearly two-thirds as long as rest of head, two large angular teeth near base of right, two angular teeth in the anterior half and one broad tooth near base of the left; pronotum very wide, much wider than head; antennae with 10 to 15 segments, the third very large and club-shaped. This species is readily recognized by the shape of the head, jaws, and third segment of the antennae.

9. Rhinotermes intermedius.

(Fig. 13 (a—d).)

Distribution.—New South Wales: Sydney and Newcastle districts.

There are no records of the occurrence of *Rhinotermes* in south-eastern Victoria and the southern coastal districts of New South Wales, but *R. intermedius* appears to be common near Sydney, where it is responsible for considerable damage to timber structures, and a closely allied form occurs in north-western Victoria. The queen and nest are unknown. Young de-alated imagos, comprising a pair or several pairs, have been found on several occasions under logs, but it is believed that reproduction does not take place until after they have penetrated fairly deeply into the soil. The winged forms leave the nests, wherever they may be situated, over a period extending from September to the end of December, and are strongly attracted to lights indoors.

IMAGO.

Length, with wings	16·00–17·00 mm. ($\frac{5}{8}$ to $\frac{11}{16}$ —)
Length, without wings	7·50 mm. ($\frac{5}{16}$ —)
Head, wide	1·77 mm. ($\frac{1}{16}$ +)
Pronotum, wide	1·48 mm. ($\frac{1}{16}$ —)

Uniform ochraceous in colour, wings hyaline, the two anteriormost veins ochraceous, the others indistinct; head broadly rounded; eyes and ocelli large, the latter not very close to the eyes; fontanelle present; postclypeus very short, elevated in front, anterior margin falling sharply to the anticlypeus; pronotum large, nearly flat, not as wide as head, markedly wider than long, narrowed posteriorly; scales of fore-wings very large, concealing about half of the much smaller scales of the hind wings; legs long and slender.

SOLDIER.

	Large form.	Small form.
Total length	6·00 mm. ($\frac{1}{4}$ —)	4·00 mm. ($\frac{3}{16}$ —)
Head, with mandibles, long	2·73 mm. ($\frac{1}{8}$ —)	1·60 mm. ($\frac{1}{16}$ —)
Head, wide	1·55 mm. ($\frac{1}{16}$ —)	0·92 mm. ($\frac{1}{16}$ —)
Pronotum, wide	1·36 mm. ($\frac{1}{16}$ —)	0·70 mm. ($\frac{1}{16}$ —)

Large form: Head and base of mandibles light orange-yellow, the latter blackish at tips; thorax and legs paler than head; head large, a little longer than wide, more or less quadrate; labrum large, wide at the base, narrowed anteriorly to the truncate apex; fontanelle large, circular, a deep groove extending anteriorly from it through the clypeus to the labrum; mandibles large, curved, with stout teeth; pronotum very short, markedly shorter than wide, not as wide as head.

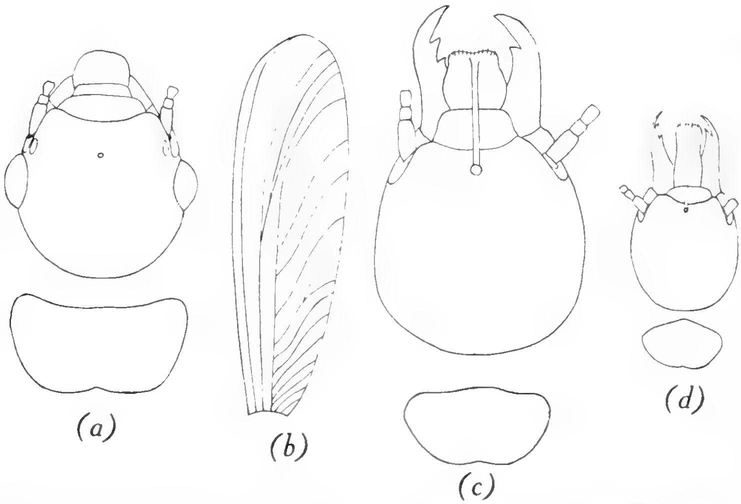


FIG. 13.—*Rhinotermes intermedius*: (*a*) Head and pronotum of imago (*b*) Wing. (*c*) Head and pronotum of soldier (large form). (*d*) Head and pronotum of soldier (smallform).

Small form: Somewhat similar to the above, excepting in size, but has a very long, narrow labrum, which reaches to near the tip of the mandibles.

10. Coptotermes lacteus.

(Fig. 14 (a—c).)

Distribution.—New South Wales: eastern districts as far north as Sydney; Victoria, excepting north-western and western districts.

The large conical mounds of the species (Plate 1) are familiar objects throughout the timbered areas of New South Wales, the Federal Capital Territory, and Victoria. When opened up, these are found to be composed of a very dense, hard clayey wall traversed rather sparsely by large and small galleries, and enclosing a large mass of equally dense papier-mache-like material. The latter is composed of particles of earth and finely triturated wood moulded to form an intricate system of continuous galleries—horizontal, diagonal, and vertical—separated by a more or less continuous, extremely irregular, and closely interlocked mass, which has been aptly described as resembling a jig-saw puzzle. At the bottom of the mass and in the middle of the mound the galleries become more crowded, and the separating walls very thin and brittle; this is the "nursery," in which the queen, eggs, and young will be found, with their attendant soldiers and workers. These mounds vary greatly in dimensions, the one illustrated measures 9 feet in height by 27 feet in circumference at the base. In all cases they have originated in a tree, stump, or log, which has been gradually destroyed by the termites and other agents, leaving only the almost indestructible mound, from which foraging parties emerge by means of subterranean burrows to attack woody material in the vicinty. How far these parties may work from their mounds has not been ascertained, but it may be mentioned that a recent writer on Malayan termites states* that termites normally travel a distance of from 300-400 yards in search of food. It is a very common occurrence to find species of *Coptotermes* in logs, in the heart of living or dead forest trees, and in fence posts and telephone poles; these may be either foraging parties or young colonies, which may, under favorable conditions, subsequently construct a typical mound of the type referred to above; *C. lacteus,* however, has not been recognized as one of the species which attack living trees.

C. lacteus occurs abundantly in mounds in Gippsland, in New South Wales, and in the Federal Capital Territory at elevations of from 50 feet above sea-level in the former States to 3,500 feet in the Brindabella Mountains, F.C.T. In the latter locality, the winged form only has been taken at elevations from 3,500 to 4,100 feet. "Swarming" has been observed during the afternoon and evening from September to November, when countless thousands of individuals have been seen to emerge from slit-like openings cut in the walls of the mounds.

IMAGO.

Length, with wings ..	..	..	14·00–15·00 mm. ($\frac{9}{16}$ — to $\frac{9}{16}$ +)
Length, without wings	..	..	6·50– 7·55 mm. ($\frac{1}{4}$ + to $\frac{5}{16}$ —)
Head, wide	..	..	1·25 mm. ($\frac{1}{16}$ —)
Pronotum, wide	..	..	1·08– 1·14 mm. ($\frac{1}{16}$ —)

Very dark brown, nearly black, somewhat paler beneath, wings smoky, with dark-brown veins, most of the latter very distinct; clypeus dark yellow; antennae dark brown; eyes and ocelli small; fontanelle present, indistinct; pronotum large, nearly as wide as head, not markedly wider than long; scales of forewings very large, markedly larger than those of the hind wings; wings very long in comparison with body.

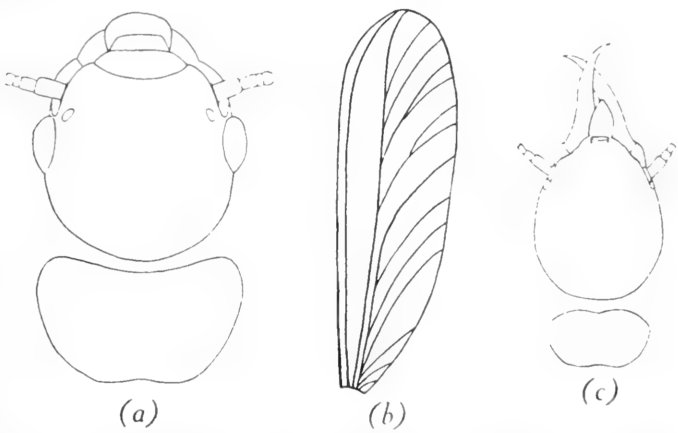


FIG. 14.—*Coptotermes lacteus:* (*a*) Head and pronotum of imago. (*b*) Wing. (*c*) Head and pronotum of soldier.

* *Malayan Forest Records, No.* 8: *p.* 46. 1930.

SOLDIER.

Total length	3·50– 3–90 mm. ($\frac{1}{8}$ +)
Head, with mandibles, long	2·07– 2·29 mm. ($\frac{1}{16}$ +)
Head, wide	1·14 –1·24 mm. ($\frac{1}{16}$ —)
Pronotum, wide	0·81– 0·96 mm. ($\frac{1}{16}$ —)

Head yellow ochre, legs and antennae paler; head pear-shaped, widest about the middle, narrowed to the base of the mandibles; mandibles long, slender, curved, the left with a stout blunt tooth near the base (concealed by the labrum), the right without teeth; labrum large, wide at the base, sharply pointed at the apex; fontanelle very large, with projecting circular rim; antennae with 15 or 16 segments; pronotum large, wider than long, and markedly narrower than head. The pear-shaped head, sabre-like mandibles, and large fontanelle are conspicuous features of the soldier of species of *Coptotermes*. A further distinguishing feature in living specimens is a globule of milk-white secretion at the fontanelle opening.

11. Coptotermes flavus.

Distribution.—Victoria (eastern half of State); New South Wales, eastern half of State as far north as Sydney.

Host Plants.—*Eucalyptus macrorrhyncha, E. melliodora, E. resinifera, E. stellulata, E. maculosa, E. micrantha, E. polyanthemos,* and *Pyrus malus* (common apple).

Little is known concerning the manner in which *Coptotermes* enter the trunks of living trees, but it is certain that the attack commences at or below ground level, and almost certainly in dead tissue. Direct communication with the soil is essential to the existence of this group of termites. In most cases only the heart of the trunk and main branches are destroyed, but in some cases the damage is much more extensive.

This species occurs very commonly in localities frequented by *C. lacteus,* though it has not been recognized until recently. It has been identified from telephone poles, dead *Eucalyptus* trees, imported softwoods, and in apple trees in a commercial orchard (Berwick, Victoria), but it appears generally to live in growing forest trees, which, in the Federal Capital Territory, at least, are very frequently completely destroyed by it. The winged forms have been found from 25th October to 7th December.

(NOTE.—Another species, closely allied to, but larger than, *C. flavus,* has been found in and around Sydney and in north-western Victoria; it is *C. acinaciformis,* a common and exceedingly destructive species throughout northern Australia. Normally, its habits are similar to those of *C. lacteus,* but it causes very considerable damage to buildings and their contents in localities in which no mounds are to be found, and it also attacks the heart of many commercial trees, including *E. resinifera* and *E. capitellata.* The colonizing flights occur from December to May.)

IMAGO.

Length, with wings	11·25–12·25 mm. ($\frac{7}{16}$ +)
Length, without wings	4·50– 5·50 mm. ($\frac{3}{16}$ — to $\frac{3}{16}$ +)
Head, wide	1·00– 1·10 mm. ($\frac{1}{16}$ —)
Pronotum, wide	0·90– 1·18 mm. ($\frac{1}{16}$ —)

Head, thorax, and wing stumps light (cinnamon) brown, sides and back of head paler; abdomen dark yellow shading to light brown; antennae, clypeus, labrum, and under surface yellow ochre; wings light smoky, veins much darker, wings relatively smaller than in *C. lacteus;* other characters as in the latter.

SOLDIER.

Total length	..	..	.. 3·50– 4·00 mm. ($\frac{1}{8}$ +)
Head, with mandibles, long	..	..	.. 1·82– 2·00 mm. ($\frac{1}{16}$ +)
Head, wide	..	..	.. 1·00– 1·10 mm. ($\frac{1}{16}$ —)
Pronotum, wide	..	..	.. 0·70– 0·80 mm. ($\frac{1}{16}$ —)

Antennae with 14, rarely 15, segments; otherwise difficult to distinguish from *C. lacteus.*

12. Heterotermes ferox.

(Fig. 15 (a—c).)

Distribution.—New South Wales, Federal Capital Territory, Victoria, South Australia, Western Australia (south-western districts).

This termite is generally found in small colonies under stones and in galleries in the soil beneath, but never in mounds of its own construction. Unlike species of *Calotermitidae,* it requires to have direct communication with the soil. It does not attack living trees. Fence posts, as well as hardwood constructional timber and imported softwoods when in contact with the soil, are sometimes extensively damaged. The colonizing flights generally take place by day during the months October to December.

IMAGO.

Length, with wings	..	..	.. 12·00 mm. ($\frac{7}{16}$ +)
Length, without wings	..	..	6·00 mm. ($\frac{1}{4}$ —)
Head, wide	..	..	.. 0·92 mm. ($\frac{1}{16}$ —)
Pronotum, wide	..	..	.. 0·72 mm. ($\frac{1}{16}$ —)

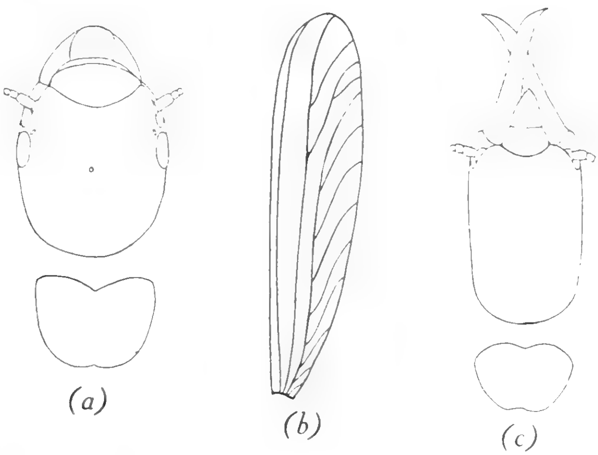


FIG. 15.—*Heterotermes ferox:* (*a*) Head and pronotum of imago. (*b*) Wing. (*c*) Head and pronotum of soldier.

Dark brown, lighter than *C. lacteus,* clypeus yellowish brown, legs and under parts mostly pale, wings light smoky with darker veins, the latter distinct; head narrow, conspicuously longer than wide, narrowest behind, widened anteriorly; eyes and ocelli very small, the former not projecting beyond lateral margins of the head; pronotum very small, flat, a little narrower than head, not markedly wider than long, markedly narrowed posteriorly; scales of the forewings much larger than those of the hindwings. The shape and small size of the head, the small eyes and small pronotum are useful distinguishing features.

Soldier.

Total length	6·00 mm. ($\frac{1}{4}$ —
Head, with mandibles, long	2·60 mm. ($\frac{1}{16}$ +)
Head, wide	0·99 mm. ($\frac{1}{16}$ —)
Pronotum, wide	0·85 mm. ($\frac{1}{16}$ —)

Head yellow, mandible ferruginous shading to black at tips, pronotum paler than head; head long and narrow, nearly parallel on the sides; mandibles very long and slender, sabre-like, curved inwards and upwards towards the tips, the left with a large blunt tooth near the base (concealed by the labrum), the right without teeth; fontanelle present, inconspicuous; labrum large conical, acutely pointed at the apex; pronotum large, flat, narrower than head, not markedly wider than long, deeply notched in front. The shape of the head and the long mandibles are useful distinguishing characters.

13. Eutermes exitiosus.

(Fig. 16 (a—d).)

Distribution.—New South Wales, Federal Capital Territory, Victoria, South Australia, Western Australia.

A very common and destructive species to timber structures. It is found generally in low domed-shaped mounds (Plate 1), rarely exceeding 2 feet in height by about 2 ft. 6 in. in diameter at the base, and composed of an intensely hard mass of triturated wood and particles of sand cemented together. The whole of the interior is honeycombed with galleries and cells, which provide accommodation for enormous numbers of insects. The "nursery" is situated near the ground in the middle of the mound, and is formed of a great number of more or less flattened galleries separated by thin layers of fragile woody material. The queen cell is situated in the lower part of the "nursery," and may be distinguished from others by its larger size (about 2 inches to 2½ inches in diameter by ¼ to ½ inch high). Such mounds as these have been found only a few feet above high-tide level on the sand hummocks of Twofold Bay, New South Wales, and at various altitudes up to 2,600 feet in the Federal Capital Territory.

Large foraging parties of workers and soldiers are commonly to be found attacking all kinds of timber structures, fence posts, twigs, logs, the bark of living and dead trees, and occasionally in the heart of living trees previously attacked by other species. In most of such cases the presence of termites is very clearly indicated by external tubes or covered-ways, under the shelter of which will be found an endless stream of insects passing to and fro between the object of attack and the soil, and thence, by subterranean galleries, to the nest.

The feeding radius of the species has not been determined, but there is some evidence that it exceeds 30 or 40 yards. There are several records of successful attacks on floor joists and floors of buildings raised on brick piers, in all of which cases the intervening space between the soil and the timber was bridged by shelter tubes. In nature, direct access to the soil is essential for the existence of this group of termites.

The colonizing flights leave the mounds at night during the months of October and November, after which the young pairs seek shelter under logs or in the crevices of trees, stumps, and posts, where they may ultimately construct a mound.

An allied species is found in the vicinity of Sydney and northwards in characteristic " negro-head " nests situated in the forks of trees and connected with soil by fragile external shelter tubes.

IMAGO.

Length, with wings	15·5–16·50 mm. ($\frac{5}{8}$ — to $\frac{5}{8}$ +)
Length, without wings	6·50– 7·50 mm. ($\frac{1}{4}$ + to $\frac{5}{16}$ —)
Head, wide	1·20– 1·25 mm. ($\frac{1}{16}$ —)
Pronotum, wide	1·14 mm. ($\frac{1}{16}$ —)

Head dark brown, clypeus, antennae and pronotum ochraceous-tawny, legs somewhat paler; wings light brown, the two anteriormost veins ochraceous, cubitus brown; eyes, ocelli and fontanelle large, the latter linear and widened anteriorly; pronotum a little narrower than head, much wider than long, narrowed to the posterior margin; scales of fore and hind wings approximately equal, small.

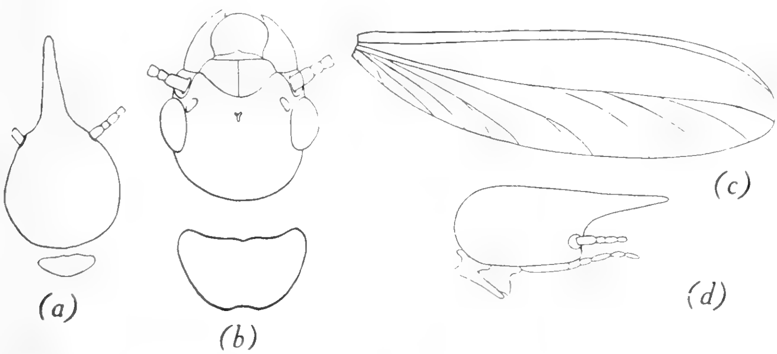


FIG. 16.—*Eutermes exitiosus*: (*a*) Head and pronotum of soldier seen from above. (*b*) Head and pronotum of imago. (*c*) Wing. (*d*) Head and pronotum of soldier seen from the side.

SOLDIER.

Total length	3·00– 3·75 mm. ($\frac{1}{8}$ — to $\frac{1}{8}$ +)
Head, long	1·76– 1·80 mm. ($\frac{1}{16}$ +)
Head, wide	1·08– 1·14 mm. ($\frac{1}{16}$ —)
Pronotum, wide	0·55 mm. ($\frac{1}{16}$ —)

Head dark brown, base of snout darker, apex of snout dark ferrugineous, antennae brown, pronotum and upper surface of body light brown; head pear-shaped, produced anteriorly into a long tapered snout; pronotum very small, markedly saddle-shaped, much narrower than head, much wider than long, the anterior margin strongly bent up and dark in colour. The shape of the head distinguishes this termite from all others mentioned previously.

14. Methods of Collecting.

For the purpose of identification it is important that specimens of all castes be secured, whenever possible. Should no alates be found at the time, a careful search should be made for the king or queen, or subsequent visits should be made with the object of finding the former. Individuals from different colonies should be kept separate, but it must be remembered that two or more distinct species may be found in the same mound or in close proximity to each other in trees, logs, &c. Full data should be recorded, as far as possible. This should include date of capture, locality, whether from a mound, log, or living tree, species of tree, position of colony in tree, &c. Termites cannot be preserved satisfactorily in a dried condition. Small vials about 3 inches long by $\frac{3}{4}$ inch in diameter, and three parts filled with 80% alcohol,* are convenient for field use. Data should be written in pencil, and the label inserted *in the vial.* A dozen or more examples of each caste should be secured. If more than a few examples are placed in the vial, it is important that the fluid be poured off after the first or second day and replaced by fresh alcohol, otherwise decomposition will render the specimens soft and difficult to deal with in subsequent operations.

Forest officers are in a position to add materially to the present scanty knowledge of the habits and distribution of those termites which infest commercial forest trees; few others have the requisite knowledge of our forest flora, or such facilities for investigating the extent of damage done by insect pests.

The identification of species of termites is not always an easy matter, but it is believed that the foregoing descriptions will enable the collector to classify the species most likely to be encountered in the ordinary course of his duties. The Division of Economic Entomology, C.S.I.R., Canberra, would be pleased to receive specimens for identification and report.

15. Glossary.

Alate ..	.. The winged reproductive male or female.
Anal lobe	.. A projecting posterior portion of the wing near the base.
Antennae	.. A pair of long, slender, many-jointed sense-organs, attached one on each side of head.
Caste ..	.. One of the several forms composing the termite colony.
Costa ..	.. The anterior margin of the wing.
Clypeus	.. That part of the head to which the labrum is attached; it is divided transversely in termites; the posterior half only is referred to in the descriptions.
Cubitus	.. The many-branched vein in the posterior part of the wing.
De-alated	.. With the wings shed.
Empodium	.. A rounded structure between the claws of species of *Calotermes.*
Ferruginous	.. The colour of rust; reddish-brown.
Fontanelle	.. A glandular opening in the mid-line of the head; often degenerated.
Heart ..	.. That portion of the centre of the tree affected by decay, or of no appreciable strength.
Hyaline	.. Colourless and transparent; like glass.
Imago ..	.. The adult or perfect insect before or after shedding wings.

* Methylated spirits may be used, but is less satisfactory.

Labrum	..	The upper lip, attached to the anterior margin of the clypeus.
Larva ..	..	An immature termite of any caste.
Mandibles	.	The principal pair of jaws in an insect.
Media ..	.	The vein between the radial sector and cubitus.
Millimetre	..	Approximately 1/25th of an inch.
Nymph ..	..	The young of the imago after the development of the wing-buds and before the appearance of the fully developed wings.
Ocelli ..	..	Colourless, simple eyes situated one on each side of the head close to the compound eyes.
Ochraceous	..	Of dull-yellow colour.
Pronotum	..	A large more or less flattened scale-like piece covering the first segment of the thorax.
Protozoa	..	Minute, single-celled animals.
Radial sector	..	The principal vein in the wing of *Calotermes;* usually with several short branches to the costa.
Radius ..	..	The vein anterior to the radial sector.
Sapwood	..	The outer layers of the wood of a tree; usually of lighter colour than the truewood.
Tarsus ..	..	The distal portion of the insect leg, consisting of from one to five segments.
Termitarium	..	The nest of a colony of termites.
Truewood	..	The term adopted to describe what is usually known as heartwood. In Australia, the central portion of a tree is very often affected by decay, and has little strength. This portion, which is really part of the heartwood, is called "heart." The terms "heart" and "heartwood" are, therefore, confusing, and that portion of the tree between the "heart," or the pith, and the sapwood is called the "truewood."
Truncate	..	Cut off.
Wing scale	..	The basal part remaining after the rest of the wing is shed.

PLATE 1.

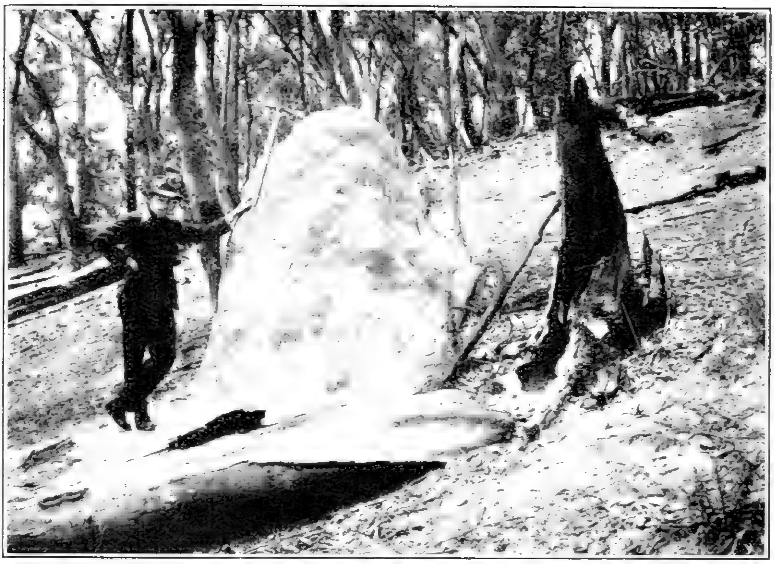


FIG. (a).—Mound or termitarium of *Coptotermes lacteus*.

FIG. (b).—Mound or termitarium of *Eutermes exitiosus*.

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