LAWES AGRICULTURAL TRUST

Rothamsted Experimental Station
Harpenden

REPORT 1918-20

with the

Supplement

to the

"Guide to the Experimental Plots"

containing

The Yields per Acre, etc.

Telegrams
Laboratory, Harpenden

Telephone
No. 21 Harpenden

Station
Harpenden (Midland)

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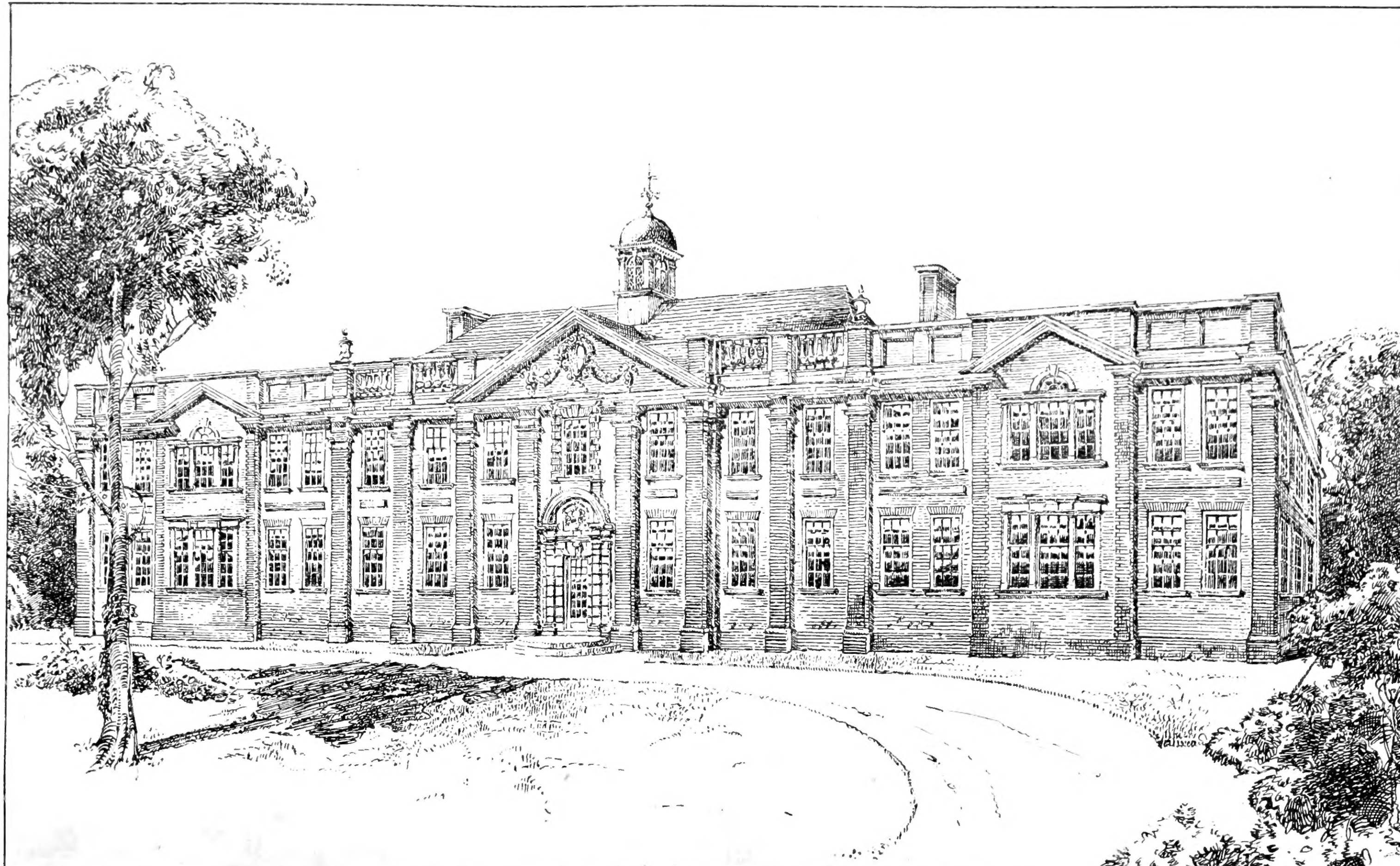

The New Rothamsted Laboratories, erected 1914-1916

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Publications of the Rothamsted Experimental Station

For Farmers

"Manuring for Higher Crop Production," by E. J. Russell, 1917. University Press, Cambridge. 4/-.

"Guide to Rothamsted Experimental Plots," 1913. John Murray. 1/-

"The Book of the Rothamsted Experiments," by Sir A. D. Hall, M.A., (Oxon.), F.R.S., Second Edition revised by E. J. Russell, D.Sc., F.R.S., (1919). John Murray. 12/6.

"Weeds of Farmland," by Winifred E. Brenchley, D.Sc., F.L.S., 1920. Longmans, Green & Co. 12/6.

For Students and Agricultural Experts

"Soil Conditions and Plant Growth," by E. J. Russell, 1921, Fourth Edition. Longmans, Green & Co., London.

"A Student's Book on Soils and Manures," by E. J. Russell, 1919. University Press, Cambridge. 6/6.

"Inorganic Plant Poisons and Stimulants," by Winifred E. Brenchley, D.Sc., F.L.S., 1914. University Press, Cambridge. 6/-.

"Agricultural Investigations at Rothamsted, England, during a period of 50 years," by Sir Henry Joseph Gilbert, M.A., LL.D., F.R.S., etc., 1895. 3/6.

"Results of Investigations on the Rothamsted Soils," by Bernard Dyer, D.Sc., F.I.C., 1902. 2/-.

"The Investigations at Rothamsted Experimental Station," by Robert Warington, F.R.S., 1891. 2/-.

"The Rothamsted Memoirs on Agricultural Science." The following are now available and may be obtained from the Station:—

Vols. I to VIII, 1847-1912 ... 30/- each, postage extra.
Vols. IX, X, 1909-20 ... ... 32/6 each, postage extra.

For General Readers

"The Fertility of the Soil," by E. J. Russell, 1913. University Press, Cambridge. 2/6.

"Lessons on Soil," by E. J. Russell, 1912. University Press, Cambridge. 2/6.

INTRODUCTION.

The Rothamsted Experimental Station was founded in 1843 by the late Sir J. B. Lawes, with whom was associated Sir J. H. Gilbert for a period of nearly 60 years. Lawes died in 1900 and Gilbert in 1901; they were succeeded by Sir A. D. Hall from 1902 to 1912, when the present Director, Dr. E. J. Russell, was appointed.

For many years the work was maintained entirely at the expense of Sir J. B. Lawes, at first by direct payment, and from 1889 onwards out of an income of £2,400, arising from the endowment fund of £100,000 given by him to the Lawes Agricultural Trust. In 1904 the Society for extending the Rothamsted Experiments was instituted for the purpose of providing funds for expansion. In 1906 Mr. J. F. Mason built the Bacteriological Laboratory; in 1907 the Goldsmiths' Company generously provided a further endowment of £10,000, the income of which is to be devoted to the investigation of the soil, thus raising the total income of the Station to £2,800. In 1911 the Development Commissioners made their first grant to the Station. Since then Government grants have been made annually, and for the year 1919-20 the Ministry of Agriculture made a grant of £9,781 in respect of Plant Nutrition and Soil Problems, and £4,023 in respect of Plant Pathology. Viscount Elveden has generously borne the cost of a chemist for studying farmyard manure since 1913, and until his death the late Mr. W. B. Randall defrayed the salary of a biologist.

The increase in the permanent trained and skilled staff has been considerable. In 1912 there were 9 members of the scientific staff, 3 of the office staff, and 12 assistants; in 1920 the scientific staff consisted of 29 members, in addition to 4 in the office, with 16 of the assistant staff, thus showing an increase of 25 during the years in question.

The laboratory expenditure has grown and almost exactly balances the income, there being only an accumulated deficit which has resulted from refitting after the War.

On the farm, however, the cost of the experimental work has latterly increased so much as to cause grave concern to the Committee. After deducting receipts the figures for net cost are :—

1911-12	£692	1914-15	£595
1912-13	£456	1915-16	£284
1913-14	£509	1916-17	£397

1918-19 - Oct. 1st to 31st March £217

1919-20 - 1½ years to Sept. 30th £1,694

For the season 1920-21 the net cost will be nearly £2,000. The period reviewed in the present report has completed the reconstruction which began in 1913, and has progressed continuously since. As a necessary preliminary, the laboratories have been entirely rebuilt, and were opened in October, 1919, by Sir Arthur Griffith Boscawen, in the unavoidable absence of Lord Lee, then Minister of Agriculture. A library has been collected and now contains some 15,000 volumes dealing with agriculture and cognate sciences. The equipment of the farm has been completed, cattle sheds erected, a tractor and other machinery added, and cultivations and cleanings necessarily neglected during the War have all been completed.

The most important part of the reconstruction has been the reorganising of the work of the Station so as to bring it into touch with modern conditions of agriculture on the one side and of science on the other. The purpose of the Station is to gain precise knowledge of soils, fertilisers, and the growing plant in health and disease, and then to put this knowledge into such a form that experts can use it. The work of the Station falls into two great divisions—the soil and the healthy plant; and the insects, fungi and other agencies disturbing the healthy relationships and causing disease. The two divisions are linked up in many ways, and every effort is made to find fresh relations between them. If farmers are ever to avoid the very serious losses they now suffer from plant diseases and pests, it will be by prevention rather than by cure.

The method adopted is to start from the farm and work to the laboratory, or vice versa. There are four great divisions in the laboratory—the biological, chemical, physical and statistical—which may be regarded as the pillars on which the whole structure rests. But the method of investigation differs from that of an ordinary scientific laboratory where the problem is usually narrowed down so closely that only one factor is concerned. On the farm such narrowing is impossible; many factors may operate and elimination results in conditions so artificial as to render the enquiry meaningless. In place, therefore, of the ordinary single factor method of the scientific laboratory, liberal use is made of statistical methods which allow the investigation of cases where several factors vary simultaneously. Thus in the crop investigations a large number of field observations are made; these are then treated statistically to ascertain the varying degrees to which they are related to other factors—such as rainfall, temperature, etc.—and to indicate the probable nature of the relationships. Thus the complex problem becomes reduced to a number of simpler ones susceptible of laboratory investigation.

It is confidently anticipated that this method will prove effective in bringing the full help of science to bear on the farmers' problems.

REPORT ON THE WORK DONE
DURING 1918, 1919, and 1920.

THE function of the Rothamsted Experimental Station is to gain exact information about soils and the growth of crops in health and disease. This information is indispensable to the teacher, indeed without a basis of precise knowledge no system of agricultural education could possibly stand: it is needed also by the advisory experts and by the expert farmer who wishes to improve on current good practice and secure better results than his predecessors. It is, however, essential that the information gained should be as correct as possible, and consequently every precaution must be taken to guard against wrong results. Wrong information has been responsible for many costly errors in the past: the deep drainage of the 'fifties and 'sixties, the burying of the surface soil by steam tackle in the 'sixties and 'seventies, and the waste arising from improper use of manures and feeding stuffs in our own time, have involved the farming community in losses amounting in the aggregate to millions of pounds sterling, and they could have been avoided had more accurate knowledge been available.

It is for this reason that the Station is staffed with highly trained scientific workers accustomed to critical examination for the detection of errors and equipped with appliances capable of giving very accurate results. The rapid development of general science and engineering during the past thirty years calls for a corresponding development of agricultural science so as to ensure that the farmer should derive the full benefit of any new improvements and at the same time be protected against proposed improvements which, as a matter of fact, are of no advantage to him.

The farm on which many of these experiments are carried out is the old Home Farm of Rothamsted—289 acres in extent—which was taken over by the Experimental Station in 1911. It is bounded on the south side by a wood, in which a certain amount of game is preserved, and in every field there are large trees, which, while adding to the picturesqueness of the landscape, detract from the productiveness of the farm. The soil is a poor stony clay (clay with flints). Under good management and moderate manurial treatment it is capable of yielding about 28 bushels of wheat and barley, 32 bushels of winter oats, 25 tons of mangolds, 6 tons of potatoes, and 10 tons of swedes per acre. Spring oats rarely succeed by reason of the spring droughts, which also adversely affect the yield of swedes. Clover is apt to make only moderate growth and to fail in patches over the field. The farm is thus one where the cultivator sees more of the difficulties than the profits of farming. It is, however, typical of much of the second rate land of England, and, as experience shows, the experimental results hold very generally throughout the country. For some time past attempts have been made to reduce the cost of production and to increase the yields.

POSSIBILITY OF REDUCTION IN COSTS OF PRODUCTION.

Full accounts of expenditure* are kept and these, when analyzed, give the following results per acre:—

	1913–14		1917–18		1918–19		1919–20	
	£	s.	£	s.	£	s.	£	s.
Wheat . . .	5	13	11	2	13	9	15	1
Oats . . .	6	9	9	14	14	11	14	12
Barley . . .	6	11	12	10	13	17	17	16
Roots . . .	18	13	29	18	37	0		—
Potatoes . . .	22	6	39	3	46	0	57	9
Grass (Hay) . .	3	16	4	19	6	0	5	17
,, (Grazing) .	2	15	2	4	3	2	3	7

* By expenditure is meant the actual money expended on the crop. No allowance is made here for interest on capital or for remuneration to the farmer beyond the sum of £100 per annum (rising to £175 in 1921) allocation for supervision and spread over 178½ acres.

THE CASH RETURNS HAVE BEEN:—

	1913-1914		1917-18		1918-19		1919-20 (estimated)	
	£	s.	£	s.	£	s.	£	s.
Wheat	7	3	18	0	14	1	19	14
Oats	8	1	12	0	31	1	15	1
Barley	6	6	11	0	24	12	18	13
Roots	10	11	19	12	23	9	—‡	
Potatoes	23	7	35	14	57	8	27	6
Grass (Hay)	2	15	—		18	11†	4	6
(Grazing)	—		2	16	3	8	—	

† Clover. ‡ Fed to Cattle.

The great increase in cost since 1917 is due in the main to the rise in wages and to the reduction in hours, which has meant not only an increased cost, but a decreased output per hour. The decreased output probably arises from the circumstance that only part of the workers' time on the farm is spent on actual crop production, the remainder being taken up with yoking and unyoking, attending to the animals, travelling from the farm buildings and back again, etc., etc. This "dead" time is the same whether the working day is 8 or 9 hours in duration, consequently the whole reduction in hours falls on the "working time." If two hours of the day is "dead" time (and this is an under-estimate) a reduction of hours from 9 to 8 means a reduction of 11% in total time, but of 14% in working time.

Further analysis of expenditure shows two great controllable items:—(1) the cost of cultivation; (2) the cost of cleaning. Our experience shows that the tractor is likely to help considerably in reducing both items. The rapid development of the tractor on the farm is the direct outcome of the war conditions. Few farmers used tractors before 1916, but many have done so since, thanks to the activities of the Machinery Section of the Food Production Department. A 20h.p. "Titan" (Internat. Harvester Co.) was purchased at Rothamsted in May, 1919, this make being selected because it was known to be reliable on heavy land, and because no English firm was then in a position to guarantee delivery in a reasonable time. This machine has given satisfactory service; it has remained in good condition with only little expenditure on repairs. Its drawback is its weight, which is approximately 60 cwts., and which, of course, renders it unsuitable for spring cultivations. For the season 1921, the Austin Company have placed at our disposal one of their new tractors which is much lighter, weighing only 30 cwts., and it is satisfactory to record that this British machine is so far doing very good work.

The tractor has proved its value in four directions:—

I. RAPIDITY OF WORK.

On heavy loams such as ours it is essential that cultivations should be carried out quickly; they are entirely dependent on the weather, and unless done when the conditions allow, they have to be postponed or curtailed considerably. The tractor hastens cultivation; it moves at the rate of 3½ miles per hour instead of 1½-2½ miles, the speed of horses; it ploughs 3 furrows at a time, and will go on working longer than horses. Our horse team takes up to a day and a-half to plough an acre; the tractor does it in 4 hours and *does it better,* for it readily works to 7 inches while the horse teams usually go only to 5 inches. The value of this additional speed has been shown in the rate at which the sowing of wheat over the whole farm has been completed. In the old days of slow horse cultivations, sowings could not be completed in October or November, and there remained always fields to be sown in January or February, according as the weather allowed. Since the advent of the tractor, however, the work has been pushed well forward and the land has all been sown in November. The dates of completion of sowing are :—

	Autumn Seeding Time.	Oats.	Wheat.
Horses only used .	1915	Oct. 16, 1915	Feb. 27, 1916
,, ,, .	1916	,, 17, 1916	Mar. 16, 1917
,, ,, .	1917	,, 27, 1917	Jan. 26, 1918
Tractor used . .	1918	,, 5, 1918	Nov. 26, 1918
,, ,, . .	1919	,, 4, 1919	Oct. 30, 1919
,, ,, . .	1920	,, 14, 1920	Nov. 11, 1920

Many of our experiments show the vital necessity on this land of sowing at the proper time; the following is an example :—

Wheat sown in time (Nov. 24th, 1915) $26\frac{3}{4}$ bushels
,, sown late (Feb. 17th, 1916) ... $19\frac{1}{4}$ bushels

II. CLEANING STUBBLES IN AUTUMN.

In the autumn of 1919 the arable fields were very weedy, as usual over wide tracts of England where cultivation had perforce been neglected for three years. Summer fallowing during 1920 would, of course, have been effective, but it was too costly; instead, therefore, the tractor was liberally used for cultivating the stubbles during harvest, and much cleaning was done during August, September and October. The effect was very striking. The weed seeds germinated in the warm moist land; the seedlings being very susceptible to injury were easily killed by cultivations; and as the cultivation was carried out before instead of after sowing the crop, it was entirely beneficial and did no damage. In consequence, the land which had been foul in 1919 became tolerably clean in 1920 in spite of the fact that a second winter corn crop was sown. The autumn cleaning was repeated in 1920 and a third corn crop sown; at the time of writing this remains free from troublesome weeds.

The advantage of this method is to give us much more latitude in cropping than we had before. Under the old horse cultivation it was imperative to grow a root crop once in 5 or 6 years to keep down weeds, and we were always rather beaten in the struggle; under the present method we can apparently grow any crops we please, unless a prolonged wet autumn should set in. This is illustrated by the Great Harpenden Field where the crops and yields per acre have been :—

Harvest of	1914	Mangolds 18½ tons, potatoes (varieties 7-10 tons)
,,	1915	Wheat (25 bush.), barley (40 bush.)
,,	1916	Wheat (26 bush.), oats (38 bush.)
,,	1917	Wheat (23 bush.)
,,	1918	Clover (weedy—1½ tons)
,,	1919	Oats (weedy), stubble cleaned (62 bush.)
,,	1920	Wheat (clean—32 bush.)
,,	1921	Wheat (still clean)

III. COST OF WORKING.

Our experience up to the present is that the cost of working with the tractor is less than with horses. For the Titan the figures for the cost of ploughing an acre of land have been :—

	1919		1920	
	By Tractor.	By Horses.	By Tractor.	By Horses.
Labour	7/7	10/2	8/9	12/6
Maintenance* . . .	—	22/6	—	28/3
Oil, Paraffin and Petrol .	7/8	—	10/7	—
Depreciation and Repairs	6/3	—	6/6	—
	21/6	32/8	25/10	40/9
Time taken . .	4 hours	1½ days		

* Including Labour Items.

IV. INCREASE IN EFFICIENCY OF LABOUR.

In our district the standard rate of wages per week has been :—

	Horseman.	Labourer.	Hours per week.
1914	18/-	16/-	57
1915	21/-	19/-	57
1916 (until May 19) . .	23/-	21/-	57
1917 (until March 23) .	24/-	22/-	57
(until Nov. 30) . .	27/-	25/-	57
1918 (until May 17) . .	31/-	28/-	57
(until Sep. 6) . .	33/-	30/-	57
1919 (until May 19) . .	42/-	32/-	48 winter 54 summer
(until Oct. 6) . .	48/6	38/6	48 winter 54 summer
1920 (until April 19) . .	48/6	38/6	48 winter 50 summer
(until Aug. 28) . .	52/6	42/6	48 winter 50 summer
(after Aug. 28) . .	56/6	46/6	48 winter 50 summer

but the efficiency of the work done with the same implements has not increased.

It would be difficult, even if it were possible, to reduce the rate of wages, but there is abundant room for an increase in efficiency. The American estimates* are :—

* K. L. Butterfield, "The Farmer and the New Day." New York, 1919, p. 9.

EFFICIENCY OF AGRICULTURAL WORKERS.

United States	100
United Kingdom ...	43
Germany	41
France	31
Italy	15

The figures may not be absolutely accurate, but it is undeniable that the British worker falls far behind the American in output. No British worker would admit that there need be so great a difference as the figures show, even if any need exist at all. The best hope for the future of the rural community is an increase in efficiency of the worker sufficient to allow for a fall in cost of production without a fall in wages.

The tractor greatly increases the output of the worker. Its effect is shown by the figures for the following times of cultivation of an acre of land measured or estimated on our farm :—

	By Tractor.		By Horses.	No. of Horses.
First Ploughing . . .	Titan	4 hours	$1\frac{1}{2}$ days	—
Cross Ploughing . . .	Austin	2 ,,	$7\frac{1}{2}$ hours	2
Cultivation . . .	Austin	$\frac{3}{4}$,,	$1\frac{1}{3}$,,	3
,, . . .	Titan	1 ,,	$1\frac{1}{3}$,,	3
Rolling 10 acres . . .	Austin	$3\frac{1}{2}$,,	$8\frac{1}{2}$,,	2
,, ,, . . .	Titan	5 ,,	$8\frac{1}{2}$,,	2

THE POSSIBILITY OF EASING THE WORK OF CULTIVATION.

The tractor is purely mechanical in its operation and consumes fuel in exact proportion to the work done by the engine. It is imperative, therefore, that useless work should be avoided as far as possible. Farmers have long known in a general way that certain manures facilitate the working of the land, and we have this year begun measurements which we hope to develop, showing the saving thus effected in energy, *i.e.*, in fuel, oil and wear and tear.

One of the most effective agents in ameliorating heavy soil is chalk. Since 1912 in several fields we have had large plots of chalked and unchalked land, each several acres in extent, and have kept records of the yields obtained. These show improvement in clover and barley, but not in potatoes, wheat, mangolds, etc. Over a six course rotation there is less financial return than might have been expected, though, of course, it is satisfactory so far as it goes.

The ploughman always declared, however, that he could work more easily on the chalked than on the unchalked land. No measure of this difference could be obtained with horse implements, but it can be done with a tractor. The Hyatt Roller Bearings Co. kindly lent us a reliable high-class dynamometer with which were taken measurements for cross ploughing land previously ploughed in autumn. These show that the effect of chalking is to increase the speed of ploughing and to reduce the draw bar pull on the three-furrow plough by no less than 200lbs.

	Cockshutt Plough.		Ransome Plough.	
Average.	No Chalk	Chalked.	No Chalk.	Chalked.
Miles per hour	2.18	2.23	1.98	2.21
Draught per plough, lb.	513	453	537	475
Per sq. in. in furrow sect'n, lb.	7.25	6.46	7.67	6.8
Draw bar pull, lb.	1538	1358	1610	1425

We propose to extend these measurements to plots treated with other fertilisers: farmyard manure, green manure, folded land, etc. The " secondary effects " of artificials, studied here by Sir A. D. Hall, may prove to have a measurable economic value when one adds up all the tractor cultivations of the year. This will form an important part of the programme of the soil physics laboratory.

THE POSSIBILITY OF INCREASED OUTPUT FROM THE LAND.

It is often urged as a reproach to agricultural experts that in spite of the multitudinous experiments of the last 20 years the output from the land is no more than it was 50 years ago. The statement is not entirely correct, but there certainly has been no increase in output from the land comparable with that in industry. One important reason is that much less cultivation is done now than was usual 50 years ago, and in consequence the crop is not given a full chance of making good growth. With the advent of the tractor it will, we hope, become possible to remedy this defect and to enable some of the newer aids to crop production to attain their full effect.

The results described in previous reports show that the output from the land is much increased by the proper use of artificial fertilisers on carefully selected suitable varieties of crops. In the case of cereals good results have been obtained by the use of spring dressings of nitrogenous manures, these being required to replace the nitrates washed out during the winter (see p. 35). Experiments, however, show remarkable differences in effectiveness according to the time of application. It is impossible on present data to formulate hard and fast rules, but as shown below it appears that a small dressing (1 cwt. sulphate of ammonia or less) may go on fairly late, while a larger dressing should go on early.

THE AMOUNT OF FERTILISER TO USE.

For many years the Rothamsted data have shown that the yield of crops increases with the amount of manure supplied, but beyond a certain point the increase is no longer proportional to the added manure. In the old experiments the unit dressing was

200lbs. of ammonium salts per acre, and the dressings were increased up to 800lbs. per acre. It was then found that the effect of the last 200lbs. of fertiliser, *i.e.*, of the increase from 600 to 800lbs. was very small and unprofitable, while the first 200lbs. had proved distinctly useful. This is in accordance with the Law of Diminishing Returns. It was assumed, therefore, that the law held for light as well as for heavy dressings of manure and a deduction was made for which the evidence was rather slender, that a small dressing of manure gave the largest rate of profit, while further dressings gave a relatively smaller return.

Recent work, however, has disturbed this view. 200lbs. per acre of ammonium salts is too large a unit for modern practice, hence more interest attaches to the effect of the smaller than to the larger dressings. Examination of the Broadbalk results shows that the largest return is given, not by the first dressing, but by the second.

The conditions of an experimental field are not quite those of practice, and accordingly a new experiment has been started to see if under ordinary conditions of farming the highest rate of profit is given by good rather than by small dressings of fertilisers. The results of the first year (1920) suggest that this may be so.

INCREASE IN WHEAT CROP, 1920, FROM SPRING DRESSINGS OF SULPHATE OF AMMONIA AND SUPERPHOSPHATE (p. 79).

	Grain: Bushels Per Acre.			Straw: Cwts. Per Acre.		
Date of Application of Manure	Feb. 10	March 6	May 10	Feb. 10	March 6	May 10
Single Dressing	Nil.	0.9	2.7	2.7	6.9	9.4
Double Dressing	7.0	—	3.7	11.7	—	12.7

While the single dressing (100lbs. sulphate of ammonia per acre) gave no appreciable increase in grain, and only a few cwts. of additional straw, the double dressing gave increases of no less than 7 bushels of grain and 12 cwts. of straw. Late application of the double dressing, however, was risky, giving an unhealthy straw liable to lodge and prone to disease.

If funds allow, the experiment will be developed on a much fuller scale: it certainly is of great importance in fertiliser practice.

INVESTIGATIONS ON ARTIFICIAL FERTILISERS.

The artificial fertiliser position has been profoundly modified by the War, and extensive factories now manufacture nitrogenous fertilisers from the air. Of these nitrate of lime, nitrate and muriate of ammonia, and nitrolim have been or are under investigation at Rothamsted.

A further important source of organic nitrogenous manure is sewage. The total amount of nitrogen contained in the sewage of the United Kingdom is estimated at 230,000 tons per annum, which is equivalent to 1,150,000 tons of sulphate of ammonia—

five times our present agricultural consumption. Under present conditions most of this is wasted, only a small portion finding its way on to the farms. A new method of dealing with sewage has, however, been devised by Dr. Fowler and his assistants at Manchester, and has been carefully tested at Rothamsted by Messrs. Richards and Sawyer. It yields an "activated" sludge, containing 6 or 7 per cent. of nitrogen and 4 per cent. of phosphoric acid, much richer than any of the older sewage sludge, and of very distinct promise as a fertiliser (p. 56). Moreover, no less than 15% of the nitrogen present in the sewage was recovered. Assuming, as seems permissible, the same percentage recovery elsewhere, the general adoption of this method would add considerably to the supplies of organic manures.

An entirely new method of treating sewage has been evolved, suitable for country houses, villages, etc., in which straw is used and a manure akin to farmyard manure is produced.

The phosphatic manures are of almost equal importance with the nitrogenous fertilisers. Considerable attention has been devoted to Basic Slag, which during the War changed considerably in character, and is not likely to go back to the old pre-war standard. A grazing experiment with sheep, and a set of hay experiments on permanent and on temporary grass land, have been started to ascertain the value of modern slags and of mineral phosphates. In addition an elaborate series of pot experiments is in hand to find out whether any constituent besides the phosphate is of value and whether the ordinary solubility test is sufficiently reliable to justify its retention. This work involves co-operation with the steel makers, and in order to develop it fully a Committee has been set up by the Ministry, composed of steel makers and agriculturists, under the Chairmanship of the Director.

Manures not only increase the crops; they bring about other changes. Phosphates improve root development, not only of swedes and turnips, but of cereals also. The Botanical Staff under Dr. W. E. Brenchley have shown that phosphates, nitrogenous and potassic manures, all cause marked increases of root development of barley, sodium nitrate whether alone or in conjunction with superphosphate being particularly effective. The root system of wheat, however, is less affected by nitrates or phosphates. Nitrogenous compounds in reasonable amount encourage early growth and help the plant in case of insect attack, while the combination of a small dressing of nitrogenous manure with a large amount of phosphates has been shown to help cereal crops, particularly oats, to mature more early in cold, wet districts. Potash increases the resistance of the mangold crop to disease and improves the sugar content of the root. Further, manures very considerably affect the composition of the herbage in grass land. Potash and phosphates encourage leguminous herbage and greatly improve the feeding quality of the herbage; nitrogen compounds encourage the grasses and largely increase the bulk of hay (p. 70 *et seq.*).

The effects of manures and cultivations on crop yields are by no means simple and straightforward. Every farmer knows the variations due to season and weather conditions. And although weather may never be controllable foreknowledge of its probable effects on the crops would be highly valuable. In order to study these effects a Statistical Department has been set up, in which Mr. R. A. Fisher and his assistant, Miss W. A. Mackenzie, have undertaken an analysis of the meteorological conditions at Rothamsted in conjunction with the crop records since 1852.

THE NEED OF ORGANIC MATTER IN THE SOIL.

However skilfully artificial manures are used it is essential on all ordinary farms to add organic matter to the soil. Four ways have been investigated for doing this.

1—*Farmyard Manure.*—Some 40,000,000 tons of farmyard manure are made by the farmers of the United Kingdom, but it is estimated by Hall and Voelcker that some 50% of the value is lost through avoidable causes. Thanks to the generous assistance of Viscount Elveden, it has been possible to retain an expert chemist, Mr. E. H. Richards, expressly for the purpose of studying this important question. Broadly speaking, the conditions to be secured in the making of the manure are sufficient supplies of nitrogen compounds and of air to allow the cellulose-decomposing organisms to break down the straw. For the storing of manure, however, it is necessary to have shelter from the rain and from access of air. The best methods of securing these conditions require working out for particular cases, which can be done after consideration of all the local circumstances.

Field experiments have shown that farmyard manure made and stored under these conditions is of higher fertilising value than the ordinary material—the crop being 10% or more beyond that given by manure kept in the usual way. An experiment has been begun in which one lot of bullocks is kept in a covered yard and an equal lot in an open yard, and the manure from both will be compared. During the War, when all sources of loss had to be studied, and as far as possible stopped, the necessary conditions were vigorously brought to the notice of farmers and Executive Committees by the Food Production Department and the Journal of the Ministry of Agriculture. Savings of several per cent. on old-established practice are possible, and every per cent. saved would mean in the aggregate some £200,000 at present prices.

A beginning has been made with a much more difficult problem—the handling of manure on a dairy farm. The conditions here are very different from those on an ordinary mixed farm where bullocks are fattened: it is desirable that the dung should be as little in evidence as possible and that the urine should be quickly and completely removed from the cow-sheds. So important is this that it must be done even if loss be thereby incurred. Two methods have been studied:—

(a) The solid excreta are removed and stored under cover and out of access of air; the liquid manure is collected in a tank and applied to temporary or permanent grass land and on the stubbles prior to the root crop.

This method is already in use on certain dairy farms, but when a careful examination was made a considerable deficit on the nitrogen account was revealed: the liquid contained only about one-half of the nitrogen expected. The loss was traced to the broken straw and solid excreta which always finds its way into the liquid; these bring about an absorption of nitrogen compounds which deprives the liquid of much of its value.

Further investigation of this absorption is going on: it may be avoidable, in which case the value of the liquid manure, already marked, could be enhanced still further. In case it seems to be unavoidable, however, a second method of procedure is being studied.

(b) The solid is collected as before, but the liquid is allowed to run through straw under conditions which encourage the absorption of nitrogen compounds. By suitable arrangement the straw increases in fertiliser value while the liquid loses part of its valuable constituents, and can more easily be sacrificed.

This method is still in the initial stages, but may prove of considerable value. Mr. Richards is carrying out the laboratory experiments at Rothamsted and the large scale experiments at Woking on Viscount Elveden's Home Farm: he has applied it also to the treatment of sewage from small installations.

2—*Artificial farmyard manure made without animals.*—Few farmers are able to make sufficient farmyard manure for their needs and some difficulty arises about the best method for utilising straw. Direct experiment shows that straw is not a useful fertiliser; indeed in many cases it depresses the crop. Once it is decomposed, however, it is of great value both for its physical and chemical properties.

Laboratory work by Dr. Hutchinson and Mr. Clayton had shown that the breaking down of the material of straw—the so-called cellulose—is effected by organisms. One of these had eluded all previous investigators, but the Rothamsted workers succeeded in obtaining it in pure culture and in studying it freely (see p. 42). In order that it may decompose straw it requires two conditions — air and soluble nitrogen compounds as food. If either of these is missing it ceases to act. Moreover, it will only attack cellulose; it is unable to feed on sugar, starch, alcohol or any organic acid yet tried. Given, however, the necessary nitrogen compounds and a sufficiency of air, the micro-organisms quickly decompose straw, breaking it down to form a black, sticky material, looking very much like farmyard manure. This has been investigated in conjunction with Mr. Richards (p. 57); further quantities are now being prepared for fertiliser tests.

3—*The clover crop* is very valuable, not only on account of the hay, but also for the effect of its root residues on the next succeeding crops. It is, however, one of the most difficult of the farm crops to grow and few farmers would claim that they could grow it as frequently as they wished. The difficulty arises from the fact that the plant depends for success on the activity of certain bacteria in its roots, and the conditions, therefore, have to be favourable both to the plant and the organisms.

Experiment shows that the clover crop is improved in four ways:—

1—By improvements in the method of sowing so as to give the seedling a good chance of establishing itself;
2—By dressings of chalk;
3—By application of phosphates, and where necessary, potash before sowing;
4—By the use of farmyard manure (p. 55).

In some of our experiments the weights of the young plants at the time of cutting the barley were:—

	Weight of young Clover plants. Cwts. per Acre	Weight of Barley. Cwts. per Acre
Control	4.8	21.2
Slag and Lime	6.7	31.7
Super and Sulphate of Potash	11.2	26.1
Farmyard Manure	10.3	28.2
Super and Farmyard Manure	15.0	26.5

We are not at present able to explain altogether this action of farmyard manure, but experiments in the bacteriological laboratory by Mr. Thornton indicate a special action of some of its constituents on the nodule organism, and seem to foreshadow interesting possibilities in the culture of the leguminous crops.

4—*Green manuring*.—The difficulty of making sufficient farmyard manure brings into prominence the need for green manuring. A field experiment has been started and the necessary laboratory work is being initiated by Mr. H. J. Page.

Although the beneficial action of a plentiful supply of organic matter in the soil is well known, precise knowledge of its mode of action is lacking. Laboratory work on humus, commenced in 1919 by Mr. V. A. Beckley (p. 37), is being extended by Messrs. H. J. Page and R. M. Winter. Refined methods for the determination of ammonia and nitrates in soils have been devised by Mr. D. J. Matthews, and are being used to study the changes occurring in the nitrogenous substances in the soil, especially after the application of green manures.

THE POPULATION OF THE SOIL. FAUNA AND FLORA.

Every farmer knows the importance of organic manure in the soil, but it is less generally realised that the effectiveness of the organic manure depends on the activity of the soil organisms, without which it would be quite useless, and in some cases harmful. Although the organisms cannot be seen by the naked eye, they are present in all fertile soils in vast numbers and in extraordinary variety. An extended survey is therefore being made on definite systematic lines with the view of learning as much as possible about the soil population. No less than 10 workers are engaged on this survey. Mr. D. W. Cutler, Miss L. M. Crump and Mr. H. Sandon study the protozoa; Mr. H. G. Thornton and Mr. P. H. H. Gray the bacteria; Dr. B. Muriel Bristol the algae; Dr. W. B. Brierley and Miss S. T. Jewson the fungi, Mr. H. M. Morris the insects, while till recently Dr. T. Goodey studied the nematodes and Mrs. Matthews the more general relationships. The ultimate aim of the agriculturist is to control this soil population in just the same way as the animal breeder has controlled and developed the original wild animals. But control is not possible without full knowledge of what the organisms are, what they do and how they live. It is this knowledge which the scientific workers are endeavouring to gain.

The first thing is to ascertain the numbers of each kind of organism present in the soil under different natural conditions. That is being done for bacteria and protozoa, and some striking relationships are observed. A new technique has been devised for counting protozoa and a new medium for use in bacterial estimations. As the organisms multiply much more rapidly than larger animals it is necessary to make the determinations frequently and regularly: counts of bacteria and 19 species of protozoa—4 ciliates, 6 amœbæ and 9 flagellates—are now made daily at Rothamsted, and it is intended to continue these for 365 consecutive days and then to look for correlations with temperature, soil moisture, rainfall, etc. Two interesting features are clearly brought out; the numbers of bacteria vary inversely with the numbers of active amœbæ, and one of the flagellates (*Oicomonas termo* Martin) shows a remarkable two days' periodicity, its numbers being high one day and low the next without any apparent external reason (p. 39).

Further, an examination of the drain gauge results has indicated the existence of soil organisms capable of absorbing nitrates, and thus competing with plants (p. 35). Algæ have been found which can do this, and Dr. Bristol is investigating their mode of life and their function in the soil. Bacteria can also take up nitrates. Large numbers of fungi have been found in the soil, and are being studied by Dr. Brierley and Miss Jewson.

The insect and other invertebrate fauna has been studied by Mr. H. M. Morris, who has taken samples each alternate week from the unmanured and the dunged plots on Broadbalk field. Each sample contained 729 cubic inches of soil: the whole was thoroughly sifted and the animals identified and counted. The average results were:—

TOTAL NUMBERS PER ACRE.

	No Manure.	Farmyard Manure.
Insects	2,475,000	7,727,000
Acari	215,000	532,000
Earthworms . . .	458,000	1,010,000
Myriapods	879,000	1,781,000
Dominant Insects 1st .	Collembola (693,600)	Ants . . (2,946,000)
2nd .	Ants . . (690,000)	Collembola (2,391,000)
3rd .	Wireworms (165,000)	Chironomid Larvæ (515,000)

The distribution at the various depths is shown in the following table of percentages of the total in each group:—

	0-1"	1"-3"	3"-5"	5"-7"	7"-9"
INSECTS:					
Manured Plot	51.5	27.2	10.9	6.4	3.8
Untreated Plot	25.3	25.0	33.0	11.1	5.5
ACARI:					
Manured Plot	48.3	25.3	20.2	5.0	1.2
Untreated Plot	59.3	23.4	14.0	3.1	--
EARTHWORMS:					
Manured Plot	23.3	37.0	22.0	10.6	7.0
Untreated Plot	23.5	41.0	18.3	11.0	5.8

The vast majority of soil organisms were found at a depth not exceeding 3 inches. Wireworms are exceptional in that they attain their maximum numbers at a depth of 5 inches to 7 inches. Manuring increases the total number of soil organisms to the extent of about 200%, but exercises no very appreciable influence upon the number of wireworms present.

THE POSSIBILITY OF THE CONTROL OF THE SOIL POPULATION.

Previous investigations have shown that heating the soil or treatment with certain poisons not only rids it of pests but actually improves its productiveness, increasing the amount of bacterial activity. This has been applied in glasshouse practice in the Lea Valley. Steaming has proved effective and so have certain chemicals, but their action is complicated by the fact that some poisons such as phenol, cresol, naphthalene, etc., are destroyed in the soil before they have been able to kill those organisms to which they are fatal. It is found that certain soil bacteria have the power of attacking or feeding on these particular poisons: they are being further studied in the bacteriological laboratory. The introduction of a chlorine atom stabilises the poison and the further introduction of a nitro-group adds considerably to its toxicity (p. 58). Much work has been done to find a suitable agent for the control of wireworms (p. 43).

INVESTIGATIONS ON THE WEED FLORA.

The accumulated data on the weed flora of arable and grass land has been worked up by Dr. Brenchley and published in book form. Connections have been traced between various groups of weeds on the one hand and soils and crops on the other, and in some cases slight changes in manurial or cultural treatment may prove efficacious in the reduction of bad weed pests. Arrangements are being made for gathering together more information from different parts of the country in order to extend the practical application of the work.

THE PHYSICAL CONDITIONS OF THE SOIL.

Much of the agricultural value of the soil depends on physical conditions, such as the ease of cultivation, the supply of air and moisture, temperature, etc. These factors, which largely determine its suitability for the growth of crops and micro-organisms, are being investigated in the Soil Physics Department under Mr. B. A. Keen.

The factors are very complex, and closely inter-related: under field conditions alteration in any one almost always produces variation in most of the others.

Soil cultivation was developed into an art when animals were the motive power on the farm. The change to mechanical power is a fundamental one, and it is by no means certain that the implements designed for horse traction will prove most suitable for mechanical traction. The study of the methods and effects on the soil of tractor cultivation has already begun at Rothamsted. The various factors contributing to the resistance offered by the soil to the plough are being analyzed in order to disentangle those due to soil conditions and those inherent in the design of the plough.

For purposes of this work it is necessary to obtain field data on soil cultivation, and on the moisture and temperature relations in the soil, from a diversity of soil types and under varying climatic conditions. The co-operation of various educational institutions situated in the country has been invited for the collection of the required information, and arrangements have been made for teachers to visit Rothamsted in order that they may become familiar with the methods of observation.

Over much of England loss of water by evaporation from the soil represents a serious source of loss to farmers. Investigations on this subject have been made and are now being extended to different soil types and varying manurial treatment. The percentage of clay in the soil has a preponderating influence on the rate of evaporation, while the manurial treatment is responsible for minor differences in the rate.

Other studies deal with the surface effects associated with clay particles, the method used being the absorption of certain dyes from their solutions; the effect of the clay fraction on various physical properties of soils; and the behaviour of the soil colloids when in contact with different liquids. It has also been shown that the experimental results obtained in America on the depression of the freezing point of soil solution measured *in situ*, are capable of quantitative investigation; a definite relation holds over a wide range of moisture content between the "free" and "unfree" water.

These results, together with earlier work in the laboratory, have formed the basis of a general review of the relations existing between the soil and its water content, which was published in 1920, and they were incorporated, together with other material, in a series of lectures on Soil Physics delivered in the University of London, and now being expanded into a Monograph (p. 59).

A detailed examination of the meteorological data collected at Rothamsted and their effect on the temperature of the soil has been published (p. 47). Material is at present being collected for a discussion of percolation and evaporation under field conditions and their relation to meteorological influences.

The investigation of soil acidity by physico-chemical methods which was started by Mr. E. A. Fisher (see p. 48) is being continued by Mr. E. M. Crowther. A hydrogen electrode and potentiometer apparatus—the gift of Robert Mond, Esq.—is now being set up, and the sources of error eliminated preparatory to a general investigation of the nature of soil acidity.

Many farms in the country are short of lime, but agricultural advisers are often in the difficulty that they cannot tell a farmer exactly how much lime the soil needs: often, indeed, they can only say that he should apply between 10 cwts. and 2 tons per acre. Of course, if farming were independent of cost, this vagueness would not matter, but the delicate financial balance under which agriculture has to be conducted leaves no margin for indecision between 10 cwts. and 2 tons. It is hoped that one result of these investigations will be to enable experts to give more definite advice than is now possible.

During the period under review, two voluntary workers have assisted in the work of the department—Mr. V. A. Tamhane, Soil Physicist to the Bombay Presidency, and Mr. H. Raczkowski, of the Palestine Experimental Station.

SPECIAL ENTOMOLOGICAL INVESTIGATIONS.

In addition to the important investigations on the insect and other invertebrate fauna of the soil already dealt with on p. 20, the Entomological Laboratory has undertaken the following work:—

(1) A study of the biological phenomena of Aphides. The results are set out on p. 49.

(2) *Chemotropism.* Dr. A. D. Imms, in conjunction with Mr. H. M. Morris, has extended his previous work (p. 48) on the responses of insects to chemical stimuli. This property opens up the possibility of controlling certain injurious insects which cannot satisfactorily be dealt with by insecticides. The method of experiment is to expose uniform amounts of various chemical substances in a series of traps for a constant length of time and to identify the species and the sex of the insects that respond.

(3) Wireworm investigations have been carried out by Mr. A. W. Rymer Roberts on the biological side, and in conjunction with Mr. Tattersfield on the chemical side (p. 43).

(4) In view of the urgent necessity for systematising the subject, Dr. A. D. Imms is preparing an advanced text book of entomology for the use of research students, which it is hoped to complete during the present year. A beginning has also been made towards the formation of insect collections which will be essential for purposes of identification and research.

(5) *Insecticides.* By common consent the subject of insecticides is not well advanced, and efforts will be made to obtain much needed fundamental knowledge. On the chemical side, Messrs. Tattersfield and Roach have investigated Tuba root (*Derris elliptica*) from which they have extracted two crystalline substances, some resins, an oil and an amorphous substance, apparently a saponin. Of these the resins and one crystalline substance are toxic. Methods have been devised for comparing the toxicities of these products, and also of different consignments of the root. In addition a chemical method for evaluating the root has been elaborated.

MYCOLOGICAL DEPARTMENT.

This department was instituted at the end of 1918 under the charge of Dr. W. B. Brierley. Although the continuity of work during the following two years has been sadly interrupted by laboratory alterations, much has been accomplished. The main investigations are summarised below.

1—*The Soil Flora.* The micro-flora of the soil is being studied by Dr. Brierley, Dr. Muriel Bristol and Miss Jewson. The algae and fungi are isolated in pure culture and cultivated *in vitro* on various food media under controlled and standardised conditions. Their identity is determined and a study made of their physiological properties and their function in the soil economy. A Rothamsted monograph on " Soil Fungi and Algae " is in preparation.

2—*The Fungal Species.* Dr. Brierley is carrying out investigations on the species concept in the fungi, this work being of fundamental importance in order that fungi—in particular those causing plant disease—may be accurately codified. Dr. Henderson Smith is employing standardised serological methods in the elucidation of this problem, this technique supplying a series of tests of a delicacy not yet obtained by chemical means. During Dr. Brierley's investigations a new form of *Botrytis cinerea* appeared, and as this has important bearings on certain basic concepts in biology it has been fully studied (p. 51).

3—*The Killing of Fungal Spores.* The greater part of remedial treatment in plant disease depends on the killing of fungus reproductive bodies by toxic agents. Such treatment is empirical for there is little knowledge of the exact relations between spores and poison. Dr. Henderson Smith is studying this problem in detail and has thrown much light upon the fundamental nature of the disinfection process (p. 52).

4—*Wart Disease of Potatoes.* This investigation is being carried out by Dr. Brierley and Miss Glynne by the aid of a special grant from the Ministry of Agriculture and Fisheries. Laboratory work is done at Rothamsted and methods are being devised to extract Wart Disease sporangia from infested soil, to evaluate the toxic effect of chemical substances upon the sporangia and to test the viability of the sporangia *in vitro* after treatment. Glasshouse and field trials are carried out at Ormskirk, where experiments on soil sterilisation, alternative hosts, manurial, cultural and other treatment are in progress.

5—*Bacterial Blackneck of Tomato.* Professor K. Nakata, of the Kyushu University of Japan, is investigating this disease, particularly from the point of view of its production by means of bacterial extract.

During 1920, Dr. Brierley represented Great Britain at the American Phytopathological Congress, and subsequently spent some months visiting educational and research institutions and the various regions of agricultural and biological importance in Canada and the United States.

WAR WORK AT ROTHAMSTED.

Some of the problems dealt with at Rothamsted during the War were described in the last Report (1914-1917). A connected account is now given so as to complete the record.

During the first year of the War (1914-15) very little direct War work was done at Rothamsted. Food was still coming into the country in large quantities and there was no great interference with food production at home. Supplies of fertilisers and feeding stuffs were ample. There was, however, fear of unemployment, and three schemes were examined at the request of the Board of Agriculture with the view of ascertaining whether they could usefully employ any considerable number of men, and if so, whether they would contribute to the national profit. These were a proposed development of Foulness Island in Essex, the suggested afforestation of the spoil heaps and pit mounds of the Black Country, and the reclamation of Pagham Harbour in Sussex. None of these schemes was further developed, though two of them—the planting of the spoil heaps in the Black Country and the reclamation of Pagham Harbour—possess aspects of permanent interest. The spoil heaps are useless and unsightly; they can, however, be planted with trees, when they take on a very different appearance, as shown by Reed Park, Walsall. Although the financial returns may not be great, the improvement in the amenities of the district would be considerable. The proposition is not agricultural, however.

The most important work began in 1916 when the food situation gave cause for much anxiety. The position was really very serious. The submarine menace was looming before us, terrible in its unfamiliarity, conjuring up visions of food shortage, if not of starvation: the only way out of the situation seemed to be the production of our own food in our own country. At the time we were producing only one-half of our total food—the remainder was coming from abroad. When the list was examined in detail the position was found to be more serious than it looked. The food produced at home included more of the luxuries than of the essentials; it included, for instance, the whole of the highest quality meat, but only one-fifth of the bread. The farmer was therefore called upon to perform a double task—he had to produce more food and different food; to give us, not one loaf out of every five that we eat, but three or four out of every five, and to do this without causing too great shortage of milk, meat, and if possible, beer. The situation presented many difficult administrative, financial and technical problems. The technical problems involving soils and fertilisers were dealt with at Rothamsted.

The fertiliser problems arose out of the necessity for making the very best use of the limited stocks of the ordinary fertilisers to which the farmer was accustomed, and of examining any and every substitute that promised help in eking out the supplies. Fortunately, a good deal of information could be drawn from the Rothamsted and other experiments as to the best way of using fertilisers on particular crops. This was systematised and put in order in a little handbook called " Manuring for Higher Crop Production," issued at a cheap price by the Cambridge University Press, so that farmers could readily obtain it. In addition, each month a series of Notes was issued in the Ministry's Journal showing how the available supplies might best be utilised.

It was more difficult, however, to give useful information about the substitutes that would be needed when the fertiliser supplies became too much reduced. Ordinarily, fertiliser trials have to be continued for two or three successive seasons before a definite opinion can be expressed on their merits: during the War, however, some sort of opinion had to be given in three or four weeks. Rapid methods of laboratory testing were therefore developed: growing seedlings were used to indicate whether (as not infrequently happened) toxic substances were present: rates of nitrification in soil were determined to find out how far the substance would yield nutrient material to the plant: farm crops were kept growing in pots to afford opportunities of testing any material that seemed promising. A considerable number of possible fertilisers were sent in for examination by the Food Production Department, the Board of Agriculture, the Ministry of Munitions, the National Salvage Council, and other bodies.

Much of the information was wanted for the purpose of economising sulphuric acid, so that the maximum quantity might be handed over to the Ministry of Munitions for the manufacture of explosives. In Peace time, the farmer had been the chief consumer of sulphuric acid; in 1917, however, the Ministry of Munitions were requiring all the acid they could find and were leaving much less than usual for the fertiliser manufacturers. The situation was serious: in pre-war days the farmer had required 870,000 tons of chamber acid per annum (equivalent to 580,000 tons of pure acid), and the extra food production programme was calling for even more than this. But the Ministry of Munitions was obdurate, and supplies were cut down at a rate which seemed to some of the more nervous to threaten a very serious situation: the production of sulphate of ammonia fell from 350,000 tons per annum to little over 250,000 tons, while that of superphosphate fell from 800,000 tons to 500,000 tons per annum.

Fortunately, a partial substitute for sulphuric acid was available in the form of nitre-cake, and although no fertiliser manufacturer liked it or had a good word for it, it seemed as if it might have to be used extensively in the manufacture of superphosphate and of sulphate of ammonia. Important and difficult technical problems were involved both at the factory and on the farm, necessitating a considerable amount of experimental work. Thanks to the co-operation of the manufacturers, working solutions of the difficulties were found, and there is little doubt that both sulphate of ammonia and superphosphate could have been made from nitre-cake had the necessity arisen. Fortunately it did not, and the situation was eased before it became too serious.

A considerable amount of work was also done in the examination of new sources of potassium compounds to take the place of the Stassfurt salts which had previously been our sole source of supply. A certain number of residues from manufacturing processes were available, but in the main they suffered from one or other of two defects: very low content of potash likely to be useful to the plant, or the presence of toxic substances. After much sorting out of possible materials, it appeared that certain blast furnace flue dusts would prove suitable, and accordingly the Food Production Department took steps to make the necessary arrangements for distribution among farmers. Considerable quantities were used, often with distinct advantage.

Investigation was also made into the possibility of using to better advantage the farmyard manure produced on the farm.

At the conclusion of the Armistice there were vast stocks of explosives in hand, and Mr. Churchill set up a small Committee, under the late Lord Moulton, to devise means of disposal. The Director was appointed to serve on this Committee and much work was done at Rothamsted to test the possibility of converting surplus explosives into fertilisers. The case of ammonium nitrate was satisfactorily dealt with (p. 54), but cordite, T.N.T., and other explosives presented more difficulties. Means were devised for preparing nitrate of lime from cordite, but there was a loss of 25% of nitrogen and a poisonous impurity (oxypyruvic acid) was always present; this, however, could no doubt have been satisfactorily eliminated had the experiments continued. The difficulty was caused not by the nitro-glycerine but by the nitro-cellulose. T.N.T. proved more difficult to convert into fertilisers, and other means of disposal were adopted.

In addition, work was carried out in connection with the agricultural development of the Belgian Congo, which H.M. the King of the Belgians recognised by conferring upon the Director the Order of the Crown of Belgium.

PUBLICATIONS DURING THE YEARS 1918-20.
SCIENTIFIC PAPERS.

CROPS AND PLANT GROWTH.

I. WINIFRED E. BRENCHLEY. "*Some Factors in Plant Competition.*" Annals of Applied Biology, 1920. Vol. VI. pp. 142-170.

The competition exhibited when plants of the same or different species grow in juxtaposition is complex and includes:—

1.—Competition for food from the soil. 2.—Competition for water. 3.—Competition for light. 4.—The possible harmful effect due to toxic excretions from the roots, if such occur.

The general effect of competition (including 1, 2, 3 above) has been studied in pot cultures, when a varying number of plants are grown in the same bulk of soil. The effect of competition for light was investigated by means of water cultures, in which a number of plants each equally furnished with food and water, were crowded together as closely as possible, while a similar set of plants was given sufficient space to avoid the shading of one plant by another.

With limited food supply the dominant factor in competition is the amount of food and particularly of available nitrogen. Other things being equal, the dry matter produced is determined by the nitrogen supply, irrespective of the number of plants drawing thereon.

With limited food supply the efficiency index of dry weight production decreases with the number of plants, as the working capacity of the plant is limited by the quantity of material available for building up the tissues.

(N.B.—"Efficiency Index" is the term employed by V. H. Blackman to express the rate per cent. at which the dry matter of a plant increases during growth.)

3.—The decrease in light caused by overcrowding is a most potent factor in competition, even when an abundance of food and water is presented to each individual plant. With barley the effect of light competition is to reduce the number of ears; to cause great irregularity in the number of tillers produced; to reduce the amount of dry matter formed; to encourage shoot growth at the expense of root growth, thus raising the ratio of shoot to root; to increase the variation in the efficiency indices of dry weight production of a number of crowded plants, lowering them on the average; to decrease the power of the plants to make use of the food supplied to the roots, as evidenced by the total quantity of nitrogen taken up by similar numbers of plants when spaced out and crowded.

4.—With adequate illumination (in barley) there is a tendency towards the production of a standard type of plant in which the relation between the number of tillers and ears, dry weights, efficiency indices, and ratios of root to shoot approximates within variable degrees to a constant standard. With overcrowding, this approximation entirely disappears.

II. WINIFRED E. BRENCHLEY. "*On the Relations between Growth and the Environmental Conditions of Temperature and Bright Sunshine.*" Annals of Applied Biology, 1920. Vol. VI. pp. 211-244.

The amount of growth made by any crop in the field and the rate at which maturity is reached are influenced by many factors, such as temperature, rainfall, season, sunlight, soil conditions and available plant food. An attempt was made to isolate some of these factors by growing a number of series of peas in water cultures throughout a period of sixteen months, results being thus obtained for all seasons of the year. Measurements of maximum and minimum temperatures and number of hours of bright sunshine were recorded throughout, and provided a basis for statistical correlations. Parallel series were usually grown, in one of which the nutrient solutions were changed weekly so that an abundant food supply was assured, whereas in the other the solution was not renewed, and the food supply was severely restricted.

It was found that growth may be divided conveniently into two well-marked periods.

(*a*) 1st period, from the seedling stage till the time that the plant regains its initial weight after the loss by respiration, *i.e.*, the time during which a casual observer would say the plant "makes no growth."

(*b*) 2nd period, succeeding the former, during which the plant is obviously making growth, and which continues till the latter ceases and dessication sets in.

The length of the first period varies inversely with the mean maximum temperature, as the rate at which assimilation is able to make good the loss by respiration increases directly with rise of temperature, up to a certain limit.

The possible amount of growth, as measured by the dry matter produced, depends entirely upon the bright sunshine and temperature when the food supply is adequate, but when the latter is limited the total growth is much less owing to the lack of material for building up the tissues. Beyond a certain limit, however, the beneficial factors of heat and bright sunshine become harmful and result in the premature death of the plant.

During the first period the rate of growth, as shown by the efficiency index, was associated with relatively warm days and nights, bright sunshine having little significant effect; the light, however, was good throughout for the season of the year. During the second period the rate was associated strongly with sunshine and warm days, but not significantly with the night temperatures, which did not fall below 32° F.

During the greater part of the year the maximum rate of growth is reached early in life, but in winter, when temperatures are low and there is little bright sunshine, the maximum rate is not attained till much later.

Plants with a restricted food supply make less total growth than those with abundant food. The falling off in the amount of dry matter produced does not seem to be gradual but is marked by definite periods, of which the incidence varies at different seasons.

During the period of actual growth, the shoot increases in weight far more rapidly than the root. Increase in shoot growth is closely associated with rise in temperature and root growth is adversely affected by low mean maximum temperatures. Rise in maximum temperature has much less beneficial action upon the roots than upon the shoots.

In early stages of growth, the amount of nitrate absorbed by the plant is relatively large in comparison with the dry matter produced, but later on more dry matter is formed in proportion to the same amount of nitrate, owing to the accumulation of the products of assimilation.

III. Winifred E. Brenchley and Violet G. Jackson. "*Root Development in Barley and Wheat under different conditions of Growth.*" Annals of Botany, 1921.

Investigations have been begun on the effect of various manures as superphosphate, sulphate of potash and nitrate of soda on the root systems of barley and wheat. Most of the experiments were made in pot cultures and the roots washed out at regular intervals to obtain the various stages of development. Two forms of roots are produced:—

1.—Much branched roots, most of which proceed from the grain. These are rather thin, long, and bear very numerous fine laterals, with root hairs only near the tip.

2.—Thick unbranched roots arising from the nodes as well as the grain, white in colour, and densely clothed with root hairs throughout their length. At a later stage these roots branch and approximate more closely to the others in appearance.

With *barley*, superphosphate encourages the development of unbranched roots, sodium nitrate having no effect. When the plants are about three months old no more unbranched roots seem to be formed. The maximum root development was reached at about the time that the ears were ready to emerge from their sheaths, *i.e.*, when pollination and fertilisation of the ovule were about to take place. With superphosphate alone and with nitrate alone, however, this maximum was reached somewhat earlier, so that apparently root growth culminated with the final stage of preparation by the plant for grain formation. In other words, during the period of purely vegetative growth the plant needs large supplies of nitrogen and ash constituents to aid in building up a strong shoot in readiness for grain formation, and the root steadily increases in order to be able adequately to cope with this demand. During the reproductive phase, on the other hand, vegetative development is reduced to a minimum, and the whole of the plant's energy is diverted towards the grain. Although nitrogen and ash constituents are just as essential as before, the area of supply is increased, as migration of these substances from the straw into the grain goes on from the outset. This reduces the strain on the root, and as such a large absorbing area is no longer required it appears that the excess provision may be got rid of by a steady process of decay, as the weight of the root steadily decreases when once the maximum is reached. The ratios of root to shoot at different periods are also discussed, a great increase of the shoot/root ratio occurring where the unbranched roots cease to be formed.

With *wheat* the unbranched roots increase in numbers less rapidly than in barley, but persist as such for a longer period.

There is in wheat nothing to correspond with the sudden disappearance of white roots which occurs in barley about 11 weeks after sowing, for in wheat the decline in white roots coincides with the decrease in weight of the complete root system, whereas in barley the formation stops suddenly when the ratio between shoot and root growth begins to change.

The paper concludes with a discussion of :—

1.—The influence of environmental conditions other than manuring upon root growth.

2.—Influence of different types of manuring upon root growth.

IV. Winifred E. Brenchley. "*The Development of the Flower and Grain of Barley.*" Journal of the Institute of Brewing, 1920. Vol. XXVI. pp. 615-632.

An account is given of the development of the ear and flower of barley from the time the young ear is about ¼-inch long until the grain is fully developed. The method of flowering in barley is to a large extent characteristic of the type, as in some cases the glumes open and in others remain closed at the time of pollination. With closed-glume flowering cross-fertilisation is of course impossible, and even with open flowering it is the exception rather than the rule.

The developmental history of the grain indicates that the awns are of considerable physiological importance, and in every barley ear the largest and heaviest grains are in the middle of the ear, and the longest awns occur on these grains, indicating some correlation between weight of grain and length of awn. The awns are essentially transpiring organs. Transpiration is most active during the development of the spike and grains, rising to a maximum just about the time the grains reach the milk stage.

V. Mary D. Glynne, B.Sc. and Violet G. Jackson, B.Sc. "*The Distribution of Dry Matter and Nitrogen in the Potato Tuber (variety, King Edward).*" Journal of Agricultural Science, 1919. Vol. IX. pp. 237-258.

King Edward Potatoes were grown in 1917 on Little Knot Wood Field, Rothamsted, lifted about the end of September, 1917, and examined in the laboratory early in 1918.

The percentage of dry matter in the potato tuber was lowest in the skin; it increased to the inner cortical layer, the zone containing the greater part of the vascular system, and decreased towards the centre of the tuber. Typical results are :—

DRY MATTER IN DIFFERENT ZONES OF THE TUBER.

Zone.	Small 54-84.5 gms.		Medium 139.5-169.2 gms.		Large 184.9–259.9 gms.		Average of 18 tubers.
	% of whole.	% dry matter.	% of whole.	% dry matter.	% of whole.	% dry matter.	% dry matter.
Skin . . .	2.78	14.29	1.85	15.08	2.83	13.44	14.01
Cortical, outer	27.54	24.86	20.29	23.43	18.11	23.36	23.71
,, inner	24.68	29.25	20.11	28.72	18.92	27.57	28.30
Medullary, outer	31.32	25.76	36.43	25.49	39.95	25.05	25.28
,, inner	13.67	20.19	21.32	18.46	20.19	17.48	18.15
Cortical, outer & inner	52.22	26.93	40.40	26.08	39.03	25.52	26.00

In each zone the proportion of dry matter is higher towards the umbilical than the terminal end of the tuber.

The percentage of nitrogen in the fresh material tends to decrease from the skin to the inner cortical layer and to increase in the medullary zone. Thus it increases from zone to zone in the opposite direction to the dry matter.

Nitrogen tends to increase with dry matter from the terminal to the umbilical end. The results are:—

	Average of 3 Small Tubers. Section			
	1	2	3	4
Skin	0.40	0.42	1.13	0.42
Cortical, outer	0.35	0.36	0.37	0.40
,, inner	0.29	0.29	0.32	0.32
Medullary, outer	0.30	0.32	0.34	0.29
,, inner	0.33	0.36	0.39	0.40
	Average of 3 Medium Tubers. Section			
	1	2	3	4
Skin	0.26	0.40	0.45	0.45
Cortical, outer	0.33	0.33	0.34	0.37
,, inner	0.29	0.30	0.33	0.35
Medullary, outer	0.30	0.34	0.37	0.38
,, inner	0.34	0.32	0.36	0.36
	Average of 3 Large Tubers. Section			
	1	2	3	4
Skin	0.45	0.36	0.51	0.54
Cortical, outer	0.33	0.34	0.35	0.41
,, inner	0.32	0.37	0.35	0.38
Medullary, outer	0.30	0.35	0.44	0.40
,, inner	0.32	0.32	0.36	0.38

Microscopical examination shows the starch grains densest in the region of the vascular system, and decreasing towards the centre and surface of the tuber.

A high degree of correlation is found between the specific gravity and percentage of dry matter of whole tubers.

For purposes of sampling the method of taking two radially opposed sectors, or diagonally opposed eighths, was far more accurate than the coring method.

VI. O. N. Purvis. "*The Effect of Potassium Salts on the Anatomy of Dactylis Glomerata.*" Journal of Agricultural Science, 1919. Vol. IX. pp. 338-365.

Stems of *Dactylis glomerata* were collected from grass plots which had received different manurial treatment as regards potash.

The yield of hay from these plots during the period of the investigation was in close agreement with the average, showing that the season was not abnormal.

The thickness of the wall, the diameter of the lumina and the ratio of the lumen to the wall were measured both in sclerenchyma and metaxylem elements. In the early stages the sclerenchyma walls were thinner where potash had been supplied, but this effect was lost as the season progressed.

The lumina were larger in plants which had received potash when nitrogenous fertilisers had not been added, but in the presence of ammonium salts, this effect was reversed.

In the xylem the thickness of the walls was unaltered, whether potassic fertilisers were added or not. When no nitrogenous manures were added the diameter of the lumen was decreased in the presence of potash, but when ammonium salts had been applied, the diameter was increased by the application of potassic fertilisers.

The addition of potassium salts produced an increased ratio of lumen to wall, but this effect gradually passed off. Presumably, therefore, potassic fertilisers reduced the strength of mechanical cells in the early stages of growth. This conclusion, however, would not hold if potassium salts affected the composition of the wall.

From these results it is concluded that the rigidity of plants supplied with potassium salts is not the result of anatomical strengthening, but must be attributed to other causes, such as the influence of the salts on the physiological condition of the plant, or on its chemical composition.

VII. R. A. Fisher. "*Studies in Crop Variation. An Examination of the Yields of Dressed Wheat from Broadbalk.*" Journal of Agricultural Science, 1921. Vol. XI.

A study of the variations in yield on Broadbalk where wheat has been grown continuously since 1843.

Three types of variation are found due respectively to (1) annual causes, primarily weather; (2) steady deterioration of the soil; (3) other slow changes, among which changes in weed flora are considered. The effect of weather is reserved for further consideration. The effects of soil deterioration and other slow changes are studied at length.

On the unmanured plot, the decrement in yield is of the order of 0.8%, or less than 1 bushel in 10 years. If this rate were maintained, the plot would still last out another 125 years. Where farmyard manure is applied there is practically no falling off in yield; this crop also shows the least variation due to weather. With complete artificials, however, there is a deterioration, but less with heavy than with light dressings of ammonium salts, which is not quite in accordance with the Law of Diminishing Returns. With incomplete artificials, however, the falling off is more marked, exceeding that of the unmanured crop. The figures are :—

Plot.	Manure.	Mean yield Bushels per acre.	Mean annual decrement Bushels per acre.	Mean annual decrement %
3 & 4	None . . .	12.27 ± .39	.097	.79 ± .16
2b.	Farmyard manure .	34.55 ± .74	.031	.09 ± .11
8	Complete artificials (treble ammonia)	35.69 ± .93	.092	.26 ± .14
7	Do. (double ammonia)	31.37 ± .90	.144	.46 ± .15
6	Do. (single ammonia)	27.58 ± .71	.141	.62 ± .19

INCOMPLETE ARTIFICIALS.

Plot.	Manure.	Mean yield in Bushels per acre.	Mean annual decrement. Bushels per acre.	Mean annual decrement. %
12	Sulphate of soda .	28.32 ± .98	.181	.64 ± .18
13	Sulphate of potash .	30.21 ± .91	.123	.41 ± .16
14	Sulphate of magnesia	27.76 ± .90	.231	.83 ± .17
7	All three sulphates .	31.37 ± .90	.144	.46 ± .15
11	None of the sulphates	22.05 ± .91	.219	.99 ± .21

The existence of the third type of variation precluded the possibility of obtaining true curves of exhaustion.

The paper contains a detailed analysis of the mathematical methods employed for the deduction of statistically homogenous material for the further study of meteorological effects.

RAIN.

VIII. E. J. Russell and E. H. Richards. "*The Amount and Composition of Rain falling at Rothamsted.*" (Based on analyses made by the late Norman H. J. Miller.) Journal of Agricultural Science, 1919. Vol. VIII. pp. 309-337.

The ammoniacal nitrogen in the Rothamsted rain-water amounts on an average to 0.405 parts per million, corresponding to 2.64lb. per acre per annum. The yearly fluctuations in lb. per acre follow the rainfall fairly closely. The monthly fluctuations also move in the same direction as the rain, but the general level is highest during May, June, July and August, and lowest during January, February, March and April.

The nitric nitrogen is on an average one-half the ammoniacal, *viz.*, 1.33lb. per acre per annum. The amounts fluctuated year by year and month by month in the same way as the ammoniacal nitrogen and the rainfall until 1910, since when there has been no simple relationship.

Reasons are adduced for supposing that the ammonia arises from several sources. The sea, the soil and city pollution may all contribute. Neither the sea nor city pollution seems able to account for all the phenomena : the soil is indicated as an important source by the fact that the ammonia content is high during periods of high biochemical activity in the soil, and low during periods of low biochemical activity.

The close relationship between the amounts of ammoniacal and nitric nitrogen suggests either a common origin or the production of nitric compounds from ammonia.

The average amount of chlorine is 2.43 parts per million, bringing down 16lbs. per acre per annum. The fluctuations closely follow the rainfall both month by month and year by year, but the general level is much higher during the months September to April than during the summer months. It seems probable that the chlorine comes from the sea, but some may come from fuel.

Since 1888, when the experiments began, to 1916, when they terminated, there has been a rise in the amounts of nitric nitrogen and of chlorine in the rain. In the case of chlorine a parallel series of determinations made at Cirencester over the same period shows a similar rise. There is no rise of ammonia, but on the contrary a tendency to drop : the sum of ammoniacal and nitric nitrogen shows little change over the period. This seems to suggest that a former source of ammonia is now turning out nitric acid : it is possible that modern gas burners and grates tend to the formation of nitric oxides rather than of ammonia.

Rain contains on an average 10 parts of dissolved oxygen per million, the amount being higher in winter than in summer : 66.4lbs. per acre per annum were brought down during the two years over which the determinations extended.

The marked difference in composition between summer and winter rainfall suggests that these may differ in their origin. The winter rain resembles Atlantic rain in its high chlorine and low ammonia and nitrate content : the summer rain is characterised by low chlorine but high ammonia and nitrate content, suggesting that it arises by evaporation of water from the soil and condensation at higher altitudes than in the case of winter rain.

CHANGES OCCURRING IN THE SOIL.

IX. E. J. Russell and E. H. Richards. *"The Washing Out of Nitrates by Drainage Water from Uncropped and Unmanured Land."* (Based on analyses made by the late N. H. J. Miller.) Journal of Agricultural Science, 1920. Vol. X. pp. 22-43.

An investigation of the results obtained by the drain gauges set up by Lawes and Gilbert in 1870.

At the beginning of the experiment the soil contained 0.146% of nitrogen, or about 3,500lb. per acre in the top 9 inches; it yielded up to about 40lb. of nitrogen per acre per annum to the drainage water. At the end of nearly 50 years it still contains 0.099% of nitrogen, or 2,380lb. in the top 9 inches, and it still gives up to the drainage water 21lb. of nitric nitrogen per acre per annum, enough to produce a 15 bushel crop of wheat, although neither manure nor crop residues have been added during the whole of the period. If the curve showing the rate of fall continued its present course and without further slowing down, no less than 150 years would be needed for exhaustion of the nitrogen.

So far as can be ascertained, the nitrogen lost from the soil appears wholly as nitrate in the drainage water. From the top 9 inches of the 20in. and 60in. gauges, the nitrogen lost has been respectively 1,124 and 1,172lb. per acre. The nitric nitrogen in the drainage water amounts to 1,247 and 1,200lb. per acre in the two gauges. These figures are arrived at by adding together the whole of the nitrate found and such estimated amounts as are possible for the first seven years before regular determinations were made, deducting nitrogen introduced by rain. The subsoil is left out of account, but evidence is adduced to show that it contributed little, if anything, to the nitrate in the drainage water.

There is no indication of fixation of nitrogen or loss of gaseous nitrogen. The soil is, however, now very poor in organic matter.

The amount of nitrate washed out is closely related to the rainfall and to a less extent to the sunshine of the preceding summer.

It is difficult to account for the slow rate of removal of nitrogen from the soil unless one introduces into the ordinary cycle some new element acting as a kind of immobiliser, absorbing nitrates or ammonia as they are produced and giving them up again later on. The case would be met if one supposed that some of the soil organisms, such as algæ, bacteria, fungi, etc., assimilated nitrates or ammonia and on their death were themselves decomposed, giving rise ultimately to nitrates again. On this view the nitrogen compounds of the soil would be supposed to break down with formation of ammonia and then nitrate, but only a portion, and not the whole, of this nitrate is liable to loss or assimilation by plants: the remainder would be taken up by organisms, temporarily immobilised, but re-formed on the death and dissolution of the organisms, when again part would be thrown out of the cycle and reabsorbed.

X. D. J. Matthews. "*The Determination of Ammonia in Soil.*" Journal of Agricultural Science, 1920. Vol. X. pp. 72-85.

An aeration method for determining the quantity of ammonia in the soil with more accuracy and in shorter time that hitherto, it being possible to recover 99.5% of added ammonia as against a recovery of 50-60% by the older methods. For details the paper must be consulted.*

The results of application to natural soils is to confirm the older conclusion that ammonia is present in minimal quantities only, but it now becomes possible to follow accurately the changes that occur when stubble or green manure are ploughed in, or when ammoniacal fertilisers are added to the soil.

*Or Soil Conditions and Plant Growth. 4th. ed. 1921, p. 349.

XI. G. A. Cowie. "*The Mechanism of the Decomposition of Cyanamide in the Soil.*" Journal of Agricultural Science, 1920. Vol. X. pp. 163-176.

This paper is of interest as showing the occurrence in the soil of changes which apparently are not brought about by micro-organisms, but by active chemical agents not yet clearly recognised.

It is known (see p. 55) that cyanamide undergoes decomposition in the soil before it can be utilised by the crop as a fertiliser. It is now shown that the decomposition proceeds in three stages: (1) cyanamide gives rise to urea; (2) urea gives rise to ammonia; (3) the ammonia is oxidised to nitrate. The first stage, the formation of urea, seems to be brought about by a chemical agent and not by micro-organisms, but the agent has not yet been discovered. The change proceeds more rapidly in clay than in sandy soils, and it does not take place at all in pure sand, in peat, or in fen soils. There is some indication that the decomposition agent may be a zeolite or active silicate. A sample of Thanet sand taken from a boring through the London Clay near Chelmsford was found, even after ignition, to be active in decomposing cyanamide into urea. This particular sand has been shown to contain a constituent resembling a zeolite in being reactive and possessing the property of softening hard water by the substitution of sodium salts and possibly potassium for those of calcium and magnesium. In following up this clue it was found that the addition of a definite zeolite prehnite to ordinary inert sand produces a mixture capable of converting cyanamide into urea.

The decomposition of urea and the oxidation of ammonia are then brought about by micro-organisms in the usual way.

XII. V. A. Beckley. "*The Formation of Humus.*" Journal of Agricultural Science, 1921. Vol. XI. pp. 69-77.

Setting out from an observation by Fenton it is shown that sugars, on treatment with acids, give rise to hydroxymethylfurfuraldehyde, which readily condenses to form a substance closely resembling humus. The author found indications of hydroxymethylfurfuraldehyde in a dunged soil and in rotting straw in which humus was being produced. He suggests, therefore, that the formation of humus in the soil proceeds in two stages:—

1.—Carbohydrates react with acids to produce hydroxymethylfurfural.

2.—Hydroxymethylfurfural condenses to form humus.

In addition, in the laboratory, there is produced some furfural and lævulinic acid.

No evidence of the formation of hydroxymethylfurfural during the decomposition of cellulose by *Spirochæta cytophaga* could be obtained.

XIII. V. A. Beckley. "*The Preparation and Fractionation of Humic Acid.*" Journal of Agricultural Science, 1921. Vol. XI. pp. 66-68.

The author finds that humus may be fractionated according to the following scheme:—

- Soil treated with Ammonia
  - Black solution Treated with Acid
    - Solution Mulder's apocrenic acid
    - Precipitate Humus Treated with Alcohol
      - Solution Hoppe-Seyler's hymatomelanic acid
        - Melanin
        - Compounds obtained by Schreiner and Shorey
      - Residue Humic acid Treated with Pyridine
        - Soluble humic acid
        - Insoluble humic acid
  - Insoluble humin

The above procedure has been repeated with rotted straw and with sugar humus, and in both cases similar fractions were obtained. The residue after pyridine extraction of sugar humus was, however, only slowly soluble in ammonia, probably having been converted into humin.

SOIL ORGANISMS.

XIV. L. M. CRUMP. "*Numbers of Protozoa in certain Rothamsted Soils.*" Journal of Agricultural Science, 1920. Vol. X. pp. 182-198.

The method used was an improvement on that previously adopted in this laboratory, but it did not discriminate between active and encysted forms. Determinations were made at intervals of about seven days of the numbers of total protozoa and bacteria in the soil of Broadbalk Plot 2, which receives 14 tons of farmyard manure in each year, and of Harpenden Field, which is typical of poor arable land. The results are plotted on curves from a study of which the following conclusions are drawn :—

1.—Flagellates, amœbæ and thecamœbæ are usually present in these soils in the trophic condition and in comparatively large numbers, so that there is an extensive population actively in search of food.

2.—The protozoan fauna is practically confined to the top six inches of the soil.

3.—There is a definite inverse relation between the numbers of bacteria and amœbæ.

4.—The amœbæ are uninfluenced by variations in the water content and temperature of the soil and by the rainfall.

5.—The richer the soil is in organic matter the richer it is in protozoa, especially in amœbæ and thecamœbæ.

These conclusions are at variance with those arrived at by the American investigators, but it is believed that the methods employed are better than those used in America.

XV. D. W. CUTLER. "*A Method for Estimating the Number of Active Protozoa in the Soil.*" Journal of Agricultural Science, 1920. Vol. X. pp. 135-143.

This method constitutes a great advance on those previously in use, since it discriminates between active and encysted forms; it has, therefore, been adopted in all the succeeding work. The soil is passed through a 3mm. sieve and two samples of 10 grams each are taken. In one the total number of protozoa (active forms plus cysts) is determined as follows: 10 grams of the sieved soil are added to 100 cc. of sterile tap water or physiological salt solution. This gives a 1/10 dilution. From it further dilutions are made as shown below.

No. 1 . .	10 gm. soil	in	100	cc. H_2O	=1/10	dilution.
2 . .	10 cc. No. 1	,,	90	,,	=1/100	,,
3 . .	5 ,, ,, 2	,,	45	,,	=1/1,000	,,
4 . .	20 ,, ,, 3	,,	30	,,	=1/2,500	,,
5 . .	20 ,, ,, 4	,,	20	,,	=1/5,000	,,
6 . .	30 ,, ,, 5	,,	15	,,	=1/7,500	,,
7 . .	30 ,, ,, 6	,,	10	,,	=1/10,000	,,
8 . .	20 ,, ,, 7	,,	30	,,	=1/25,000	,,
9 . .	20 ,, ,, 8	,,	20	,,	=1/50,000	,,
10 . .	30 ,, ,, 9	,,	15	,,	=1/75,000	,,
11 . .	30 ,, ,, 10	,,	10	,,	=1/100,000	,,

Nutrient agar is poured into sterile Petri dishes. When the medium has solidified, the dishes are inoculated in pairs with 1 cc. of each dilution. Incubation at 20° is continued for 28 days, and the plates examined at intervals of 7 days, 14 days, 21 days and 28 days. This long period of incubation is necessary in order to ensure accurate results.

In the other 10 gram sample the cysts only are determined, advantage being taken of the fact that they survive treatment with 2% hydrochloric acid while active forms do not. The soil is therefore treated with sufficient 2% HCl to neutralise the carbonate present and still leave an excess of unchanged 2% acid. The acid is allowed to act overnight. After treatment, the number of protozoa in the sample is ascertained by the dilution method; this gives the number of cysts since the acid has killed all the active forms, leaving most of the cysts unharmed. The number of cysts subtracted from the total number of organisms given by the first count gives the number of active protozoa per gram of the soil sample.

XVI. D. W. CUTLER and L. M. CRUMP. "*Daily Periodicity in the Numbers of Active Soil Flagellates, with a brief note on the Relation of Trophic Amœbæ and Bacterial Numbers.*" Annals of Applied Biology, 1920. Vol. VII. pp. 11-24.

Using the preceding method, it was found that the numbers of protozoa varied so rapidly that weekly counts did not fairly represent the changes taking place. A series of daily counts was therefore projected and continued for 28 days—from February 9th to March 8th. During the last 14 days the bacteria also were counted. The following conclusions were drawn :—

1.—There is a daily variation in the number of trophic forms of the three species of flagellates, *Oicomonas sp.* (Martin), *Cercomonas longicauda* and *Bodo sp.*, in the soil of arable fields.

2.—The numbers of bacteria and trophic amœbæ in the soil are correlated, varying inversely over a period of 14 days.

3.—Temperature and rainfall appear to have no influence on the number of active protozoa in the soil.

(Note.—In view of the importance of these results counts were begun on July 4th, 1920, and have gone on daily ever since: it is proposed to continue these for 365 consecutive days.)

XVII. D. W. Cutler. "*Observations on Soil Protozoa.*" Journal of Agricultural Science, 1919. Vol. IX. pp. 430-444.

It is shown that soil possesses a remarkable power of retaining protozoa. When a suspension of protozoa is shaken with soil all the organisms are withdrawn until the saturation point is reached, after which, for the first time, the supernatant liquid contains protozoa. Some of the results are :—

	Active flagellates and amœbæ, millions per c.c. of suspension.			
Before shaking with soil	.56	1.64	1.98	2.80
After ,, ,, ,, ...	Nil.	Nil.	0.29	1.04
Number taken up per gram of soil .	All	All	1.69	1.76

Until the soil has absorbed 1.7 millions per gram there is complete retention of the organisms.

One gram of coarse sand is capable of withdrawing approximately 145,000 amœbæ and flagellates from a suspension of any strength. Fine sand withdraws approximately 980,000: soil and partially sterilised soil 1,650,000, ignited soil 1,500,000, and clay 2,450,000 per gram of material in each case.

These figures are constant for given material and organisms, and are independent of the concentration of the suspensions, the time of action, or whether the suspension contains cysts or active forms of the amœbæ and flagellates investigated. Also the action is the same when the experiment is performed with a suspension of living or dead organisms.

Experiments with the ciliate—*Colpoda cucullus*—show that coarse sand retains 27,000; fine sand 185,000; soil and partially sterilised soil 270,000 and clay 450,000 per gram of material.

The importance of this work arises from the fact that some of the previous investigators have examined soil suspensions under the microscope for protozoa, and have drawn certain conclusions from failure to find active forms. The present investigation shows that the method is unreliable and the conclusions, therefore, not justified. This objection does not apply to the dilution method described above.

XVIII. W. F. Bewley and H. B. Hutchinson. "*On the Changes through which the Nodule Organism (Ps. radicicola) passes under Cultural Conditions.*" Journal of Agricultural Science, 1920. Vol. X. pp. 144-162.

Under certain cultural conditions the nodule organism from the roots of red clover, broad bean, lucerne and lupin exhibits a tendency towards granular disintegration of the cell with the formation of small non-motile coccoid bodies, about 0.4μ diameter.

In the culture media ordinarily in use these coccoid bodies are not formed extensively, but cultivation on soil extract media rapidly leads to their production, until finally they constitute the predominant type in the culture.

A life-cycle consisting of five stages is described :—

1.—*The pre-swarmer form (non-motile).* When a culture of the organism is placed in a neutral soil solution, it is converted after four or five days into the pre-swarmer form.

2.—*Second stage, larger non-motile coccus.* In presence of saccharose, certain other carbohydrates and phosphates, etc., the pre-swarmers undergo a change. The original coccoid pre-swarmer increases in size until its diameter has been doubled, but still remains a non-motile coccus.

3.—*Swarmer stage, motile.* The cell then becomes ellipsoidal and develops high motility. This form is the well-known " swarmer " of Beijerinck.

4.—*Rod-form.* Proceeding in an " up-grade " direction, the swarmer becomes elongated and gives rise to a rod-form, which is still motile but decreasingly so. So long as there is sufficient available carbohydrate in the medium, the organism remains in this form.

5.—*Vacuolated stage.* When, however, the organism is placed in a neutral soil extract or the available carbohydrate becomes exhausted, it becomes highly vacuolated and the chromatin divides into a number of bands. Finally, these bands become rounded off and escape from the rod as the coccoid pre-swarmer.

The formation of the coccoid bodies (pre-swarmers) may also be induced by the addition of calcium or magnesium carbonates to the medium or by placing the organisms under anærobic conditions. Of a considerable number of compounds other than carbohydrates, calcium phosphate alone was capable of bringing about the change from pre-swarmers to rods.

The organism also appears to be affected greatly by the reaction of the soil. In the main, the normal rod rapidly changes into the pre-swarmer form in calcareous soils ; acid soils cause the production of highly vacuolated cells and eventually kill the organism, while a slightly alkaline soil was found to be capable of supporting vigorous growth without altering the form of the cells.

The effect of various temperatures on the rapidity of pre-swarmer formation has been studied. Relatively high temperatures (30° and 37°) either prevent or postpone the entrance of down-grade changes.

XIX. H. B. HUTCHINSON and J. CLAYTON. "*On the Decomposition or Cellulose by an Aerobic Organism (Spirochæta cytophaga n. sp.).*" Journal of Agricultural Science, 1919. Vol. IX. pp. 143-173.

Examination of Rothamsted soils on different occasions has revealed the presence of an organism capable of breaking down cellulose with comparative ease. Morphologically, the organism appears to possess greater affinities with the Spirochætoideæ than with the bacteria, and the name *Spirochæta cytophaga* is therefore suggested.

While the Spirochæt is capable of considerable vegetative growth as a sinuous filamentous cell, it also appears to pass through a number of phases which terminate in the production of a spherical body (sporoid) which differs in a number of respects from the true spores of the bacteria. Germination of the sporoid again gives rise to the filamentous form, which possesses perfect flexibility and is feebly motile. The latter does not apparently possess flagella.

Spirochæta cytophaga is essentially aerobic; its optimum temperature is in the region of 30°. Both the thread and sporoid stages are killed by exposure to a temperature of 60° for ten minutes.

The nitrogen requirements of the organism may be met by a number of the simpler nitrogen compounds—ammonium salts, nitrates, amides and amino-acids. Peptone is also suitable in concentrations up to 0.025%. Stronger solutions, *e.g.*, 0.25% lead to a marked inhibition of growth. The organism fails to grow on the conventional nutrient gelatine or agar.

Comparative experiments with a number of higher alcohols, sugars and salts of organic acids show that none of these is capable of meeting the carbon requirements of the organism. Cellulose is the only carbon compound with which growth has been secured.

Although none of the monoses, bioses and other carbohydrates is able to support growth, many of them exert an inhibitive action on cellulose decomposition if present in other than very low concentrations. This may be correlated with the reducing properties of the carbohydrate. Maltose, for example, has been found to be approximately 70 times more toxic than saccharose.

Of the various by-products of the action of Spirochæta cytophaga may be mentioned: (*a*) a pigment possessing relations to the carotin group, (*b*) mucilage which does not give rise to optically active compounds on hydrolysis, and (*c*) small quantities of volatile acids.

Evidence is also adduced to show the relation of cellulose decomposition to the assimilation of atmospheric nitrogen.

XX. A. W. RYMER ROBERTS. "*On the Life History of Wireworms of the genus* AGRIOTES, *Esch., with some Notes on that of* ATHOUS HÆMORRHOIDALIS, F." Part I. Annals of Applied Biology, 1919. Vol. VI. pp. 116-135.

The biology and life history of the common "wireworm" was studied during the years 1916-1919. In England and probably also in Wales and Scotland, *Agriotes obscurus* is generally the commonest species. The adult beetles hatch from the pupa in August or September and remain in hibernation during the winter. About the middle of May they emerge, feed on the nectar or pollen of flowers and do little or no damage, at least in this country. Oviposition takes place generally from the end of June to the middle of July. The eggs of three species of *Agriotes—obscurus, sputator* and *sobrinus* and *Athous hæmorrhoidalis* were obtained from the soil of pots, in which the beetles had been confined, at depths varying from $\frac{1}{4}$-inch to 2 inches, either in batches or singly. Attempts to obtain ova from *Ag. lineatus* failed, but from other sources it is known to deposit its eggs in a similar position, and probably the presence of grasses, whether cultivated or growing as weeds, is essential to all five species. This conclusion points to the necessity for clean cultivation in the control of wireworms.

The larvæ on emergence at once burrow into the soil. All are pale in colour and so small (1-2.75mm.) as not to be generally recognised during their first year. The first moult of *A. obscurus* takes place in June, the second in July or August, and it is believed that the larvæ in general moult twice a year, in April or May, and again between July and September. In their first year, the larvæ appear to feed chiefly on partially decomposed vegetable matter and perhaps to some extent on the small roots of living plants, but no evidence of definite damage was obtained. In the later stages they feed on almost any crop and on many weeds. They appear to attack mustard only in the absence of more suitable food, though they are frequently found at the roots of charlock. The larvæ can subsist for a long time on the decaying organic matter in the soil and are able to withstand immersion in water for prolonged periods. During the winter they may be found close to the surface in grass land. But in fallow land they undergo a period of hibernation, sometimes as much as 2ft. from the surface.

Agriotes obscurus has a larval life history extending to five years, as was originally stated by Bierkander.

Pupation takes place in an earthen cell prepared by the larvæ at a depth of from 1 inch up to $7\frac{1}{2}$ or more inches. The pupal stage extends over a period of about 3 weeks, pupæ being found from the end of July to the middle of September.

Wireworms under natural conditions are not parasitized to any great extent. A Proctotrupid, probably *Phænoserphus fuscipes* Hal. was bred from *Athous hæmorrhoidalis,* and a Proctotrupid was also found within a larval *Agriotes obscurus.* The latter species was also found to be the host of a fungus of the genus *Isaria.*

XXI. F. Tattersfield and A. W. R. Roberts. "*The Influence of Chemical Constitution on the Toxicity of Organic Compounds to Wireworms.*" Journal of Agricultural Science, 1920. Vol. X. pp. 199-232.

The relationship between chemical constitution and toxicity to wireworms of organic compounds is found to be of a two-fold nature.

The general effect of a group of compounds of the same type is directly determined by the chemical constitution of the type.

The particular effects of individual members of the groups are limited by their physical properties such as volatility, etc., which may be regarded as indirect consequences of their chemical constitution.

The aromatic hydrocarbons and halides are on the whole more toxic than the aliphatic hydrocarbons and halides. The groups that influence toxicity most when introduced singly into the benzene ring are in order of importance the methylamino (most effective), dimethylamino, hydroxy, nitro, amino, iodine, bromine, chlorine, methyl groups (least effective). But this order is modified in presence of another group; thus when there is a CH_3 already present in the ring the order becomes chlorine (side chain), amino, hydroxy, chlorine (ring), methyl. Chlorine and hydroxy groups together give rise to highly poisonous substances considerably more effective than where present separately. The association of chlorine and nitrogroups in chlorpicrin give rise to one of the most toxic substances tested. Methyl groups substituted in the amino group of aniline increase toxicity more than if substituted in the ring.

Compounds with irritating vapours have usually high toxic values, *e.g.*, Allyl isothiocyanate, chlorpicrin, benzyl chloride. The toxic values of these substances are not closely correlated with their vapour pressures or rates of evaporation.

There is a fairly close relationship between toxicities and the vapour pressure, rates of evaporation and volatilities of compounds of the same chemical type. In a series of similar compounds decreases in vapour pressure and volatility are associated with an increased toxicity. A possible explanation is that condensation or absorption takes place along the tracheal system when insects are submitted to the action of these vapours. On exposure once more to the open air these vapours diffuse out into the atmosphere, the rate at which they do so being a measure of the rapidity with which the insect recovers.

A limit is put upon toxicity by the decrease in vapour pressure, when it sinks too low to allow a toxic concentration in the vapour phase. Chemically inert compounds boiling above 170° C. are generally uncertain in their poisonous effects on wireworms after an exposure of 1,000 minutes at 15° C. Nearly all organic compounds boiling above 215° C. are uncertain in their action, while those boiling above 245° C. are non-toxic. These limits depend on the resistance of the insect, the length of exposure and the temperature at which the experiment is carried out.

XXII. N. N. Sen Gupta. "*Dephenolisation in Soil.*" Journal of Agricultural Science, 1921. Vol. XI.

It is found that phenol and the cresols disappear when added to soil. Three actions seem to be involved:—

1.—An instantaneous disappearance which appears to be non-biological, but its exact nature has not yet been elucidated; apparently it varies directly with the clay content of the soil.

2.—A slow decomposition which continues till all the phenol is exhausted. This is apparently largely brought about by micro-organisms capable of utilising phenol as a source of energy.

3.—There appears, however, to be some non-biological slow decomposition also, since the decomposition in unmanured soil poor in micro-organisms is much slower than in manured soils, and altogether different in character.

Autoclaving the soil at 130° for 20 minutes destroys the cause or causes of the decomposition altogether, but the action proceeds, although much more slowly, than in untreated soil, in the presence of a considerable amount of toluene and mercuric chloride.

Partial sterilisation by treatment with toluene which was evaporated before the addition of phenol increases the rate of decomposition, but steaming does not.

The decomposition takes place even in soil air-dried to 2.4% moisture, but it is extremely slow compared with the rate in normal soil.

When successive doses of phenol are applied to the same soil, each dose is decomposed at a higher rate than the preceding one. This is entirely in accordance with a decomposition mainly biological in character. The same effect has been observed in the case of *m*-cresol.

The treatment of the soil with sulphuric acid (50% by volume) either before or after the addition of phenol greatly augments the instantaneous loss, which may amount to 90% in case of phenol This loss is not affected by autoclaving.

CONDITIONS DETERMINING ENVIRONMENTAL FACTORS IN THE SOIL.

XXIII. B. A. Keen. "*A Note on the Capillary Rise of Water in Soils.*" Journal of Agricultural Science, 1919. Vol. IX. pp. 396-399.

A simple formula for the theoretical maximum rise in an ideal soil, composed of closely packed and uniform spherical grains, may be obtained from a consideration of the triangular pores existing in such a soil. The formula reduces to $h=\frac{.75}{r}$ where h = height of rise and r = radius of spherical grain. The capillary rises given in the following table are calculated on the assumption that a soil is made up entirely of one given soil fraction, and not of a mixture of fractions, and the particles are taken as closely packed spheres :—

Soil Fraction	Diameter in mm.		Capillary Rise in cms.		Average Rise in Ft.
	Max.	Min.	Min.	Max.	
Fine gravel .	3	1	5	15	$\frac{1}{3}$
Coarse sand .	1	.2	15	75	$1\frac{1}{2}$
Fine sand .	.200	.040	75	375	$7\frac{1}{2}$
Silt . . .	.040	.010	375	1500	$31\frac{1}{4}$
Fine silt . .	.010	.002	1500	7500	150
Clay . .	.002	—	7500	—	150 upwards

XXIV. B. A. Keen. "*A quantitative Relation between Soil and the Soil Solution brought out by Freezing-point Determinations.*" Journal of Agricultural Science, 1919. Vol. IX. pp. 400-415.

An analysis is made of the experimental data accumulated by Bouyoucos and others in their investigations of the freezing-point depression of the soil solution *in situ* under various conditions. Bouyoucos finds that the soil solution in quartz sand and extreme types of sandy soil behaves approximately like dilute solutions, the freezing-point depression varying as the concentration, or, in the present case, inversely as the moisture content, *i.e.*,

$$M_n D_n = K$$

where K = constant, D_n = freezing-point depression at moisture content of M_n. In the vast majority of soils, however, the freezing-point depression increases much more rapidly with decreasing moisture content than this equation would imply, and Bouyoucos was led to suppose that the soil rendered a definite amount of water "unfree," in the sense that it did not take part in the freezing-point depression.

This hypothesis is quantitatively examined in the present paper, and it is shown from Bouyoucos' experimental data that :—

1.—The water rendered unfree is not a constant amount, but varies with the moisture content.

2.—A definite relation exists between the free, unfree and total moisture, expressed by the equations :—

$$Y_n = cM_n^x$$

$$Z_n = \frac{1}{c^{\frac{1}{x}}} Y_n^{\frac{1}{x}} - Y_n$$

where c and x are constants for any one soil,

M_n = total moisture content,
Y_n = free water,
Z_n = unfree water.

XXV. B. A. Keen. "*The Relations existing between the Soil and its Water Content.*" Journal of Agricultural Science, 1920. Vol. X. pp. 44-71.

This paper is a general survey of the literature of the subject. Until recently, most of the experimental data was interpreted on the assumption that the moisture was distributed in a thin film over the surface of the soil grains. The water in this film was divided into three classes: hygroscopic, capillary and gravitational. The gravitational water could drain away into the subsoil, the capillary water was retained by the soil, and was capable of movement therein, and the hygroscopic moisture was assumed to be incapable of movement under capillary or gravitational forces.

It was found that these divisions were insufficient to explain the observed facts, and a number of auxiliary divisions and equilibrium points were introduced, mainly by American workers. This carried with it the serious defect that each sub-section was more or less detached from its neighbours, and thus the hypothesis did not give a complete picture of the *continuous* processes operating between soil and its moisture content when the latter varied over wide limits. Endeavours were therefore made to link up the sub-divisions by means of cross-relations between the variables, but they were mainly applicable over some small range of moisture content or to some approximate equilibrium values.

The development of the study of colloids rendered it possible to consider the relations between soil and its moisture content by an alternative hypothesis which would stress their continuous nature. It is now considered that the soil particles are coated with a colloidal complex, derived from the clay and the organic matter. In the concluding section of the paper a number of investigations are considered and interpreted on this hypothesis, and some of the most promising future lines of work are indicated.

XXVI. B. A. KEEN. *"The Physical Investigation of Soil."* Science Progress, 1921. Vol. XV. pp. 574-589.

This is a general account of the scope of physical science in investigations on soil. It deals with the dimensions of soil particles and the manner of their arrangement in the soil, the temperature, moisture, and atmospheric relations in the soil, and indicates also the great need for research on methods of cultivation and the effect on the soil of the form of implement used, in view of the important changes in farming practice brought about by the introduction of the tractor.

XXVII. B. A. KEEN and E. J. RUSSELL. *"The Factors determining Soil Temperature."* Journal of Agricultural Science, 1921. Vol. XI.

The purpose of this paper is to discuss the factors influencing soil temperature and the extent to which other measurements (air, temperature, hours of sunshine, etc.) can be utilised in cases where direct determinations of soil temperature are not made.

An analysis has been made of one year's records given by a special recording thermometer embedded at the 6in. depth in bare soil, together with continuous records of air temperature and hours of sunshine; these have been supplemented by daily readings of rainfall, radiation, and soil temperature at the 12in. depth. The extent of the temperature rise at the 6in. depth is largely determined by the amount of solar radiation reaching the earth's surface (correlation co-efficient .877 $\pm$.009). As would be expected, the hours of sunshine also provide a good measure of this radiation.

The maximum temperature at the 6in. depth during the summer months is about equal to that of the air, and the minimum temperature is from 6°—8° C. higher than the air minimum.

During this period, the conditions therefore resemble those in a 20° C. incubator.

In the winter months the minimum temperature at the 6in. depth is usually about 2°—3° C. higher than that in the air, and the maximum temperature is a little below the maximum air temperature. The effect of rainfall is generally to diminish the rise of temperature, but the relation is by no means exact. No evidence was found supporting the belief that spring rains warm the soil; on the other hand, autumn rains apparently prevent the soil from cooling as much as it would otherwise have done.

There is no satisfactory substitute for a recording soil thermometer, but a fair estimation of the mean daily temperature at the 6in. depth can be obtained over the greater part of the year by regarding the maximum air temperature as the maximum soil temperature, and the 12in. depth soil temperature at 9 a.m. as the minimum, and then taking the mean.

The relations between the daily temperature rise in the soil and the air have been studied in detail by following the changes in the ratio $\frac{\text{soil amplitude}}{\text{air amplitude}}$ from day to day. These ratios fall into a well-defined frequency curve whose maximum occurs between the values .2—.3. This range of the ratio is prevalent in spring and early summer, and also in early autumn. A similar curve is given by the ratios of the daily cooling of soil and air, the maximum in this case being between .3—.4. The ratio $\frac{\text{soil amplitude}}{\text{air amplitude}}$ of course alters when either, or both, numerator and demominator change. A series of relations between these changes, both for individual and averaged values is given in the paper.

XXVIII. E. A. Fisher. "*Studies on Soil Reaction—I. A résumé.*" Journal of Agricultural Science, 1921. Vol. XI. pp. 19-44.

A critical account of the various hypotheses put forward to explain the phenomena of soil acidity and the methods that have been suggested for estimating it. All present methods are shown to be defective. The hydrogen ion concentration gives useful indications, but the titration methods, lime requirement methods, etc., are defective because the lime requirement is really very complex, being made up of two factors; the lime required to neutralise soil acids, and the lime actually absorbed by the soil. It is impossible at present to differentiate these or to compare with any degree of strictness one soil or one base with another.

XXIX. E. A. Fisher. "*Studies on Soil Reaction—II. The colorimetric determination of the hydrogen ion concentration in soils and aqueous soil extracts.*" Journal of Agricultural Science, 1921. Vol. XI. pp. 45-65.

Details to be observed and difficulties to be overcome in the colorimetric determination of the hydrogen ion concentration in soils. It is shown that the fineness of division of the soil is of considerable importance.

PLANT PATHOLOGY.

XXX. A. D. Imms and M. A. Husain. "*Field Experiments on the Chemotropic Responses of Insects.*" Annals of Applied Biology, 1920. Vol. VI. pp. 269-292.

During the course of these experiments the insects attracted consisted almost exclusively of *Diptera; Hemiptera, Coleoptera* and *Neuroptera* were unrepresented. A small number of *Noctuid Lepidoptera* entered the traps, which however were not adapted for such relatively large insects as many *Lepidoptera*. Beer, cane molasses, and mixtures of these two substances are powerful chemotropic agents for various *Diptera*. Ethyl alcohol, in various concentrations, exhibited little or no chemotropic properties, but with the addition of small amounts of butyric, valerianic or acetic acids it exercised a powerful attraction. Aqueous dilutions of the above acids were not attractive, the respective esters probably being the attractive agents in each case. The remaining substances utilised in these experiments were found to exhibit little or no positive chemotropic properties. Out of considerably over 3,000 *Diptera* attracted during the course of these observations, by far the greater number pertained to one or other of the five families, *Rhyphidæ*, *Mycetophilidæ*, *Sepsidæ*, *Muscidæ* and *Anthomyidæ*. As a general rule, members of both sexes of a species were attracted irrespective of the chemotropic agent employed. In the majority of instances, males predominated over females, but in no case where the number of individuals of a species attracted exceeded 20 was the disproportion greater than 2.9 males to 1 female. *Rhyphus punctatus*, *Hylemyia strigosa* and *Calliphora erythrocephala* were the dominant species attracted.

XXXI. J. Davidson. "*Biological Studies of Aphis rumicis L.*" Part I.—"*Description of the Species and Life History.*" Bull. Entom. Res., Vol. XI., 1921.
"*Biological Studies of Aphis rumicis L.*" Part II.—(a) "*Appearance of the Winged Forms*"; (b) "*Appearance of the Sexual Forms.*" Proc. Roy. Dublin Soc., 1921.
"*Biological Studies of Aphis rumicis L.*" Part III.—(a) "*Reproduction of Aphis rumicis on different Host Plants*"; (b) "*Influence of Food Plants on the Characters of the Species*"; (c) "*Influence of Temperature and Humidity on the Development of the Species.*" Annals of Applied Biology, Vol. VIII., 1921.

The life history of *Aphis rumicis* is as follows :—

The ova are laid by sexual females on the winter host *(Euonymus)* during September and October [1]. These hatch out in March and April, and the *Fundatrices* produce the first viviparous generation on the winter host. Eventually, w.v.[2] (*migrantes*) develop, which migrate to the intermediate hosts, such as beans, poppies, etc. On these latter plants, they produce a.v. (*alienicolæ apteræ*). Eventually, w.v. (*alienicolæ alatæ*) are produced which fly to other intermediate hosts, of the same kind or different species, such as *Chenopodium*, Mangolds, Beet, *Capsella bursa-pastoris*, *Rumex*, etc. This infestation of the intermediate hosts continues throughout the summer months.

In September, certain of the *alienicolæ apteræ (sexuparæ apteræ)* produce winged sexual males, and at the same period certain of the *alienicolæ alatæ (sexuparæ alatæ)* which morphologically resemble the earlier winged forms but are physiologically different, fly back to the winter host, and there produce apterous females. The males fly back from the intermediate hosts to the winter hosts, the cycle being thus closed.

(1) It is highly probable considering the wide distribution of *Aphis rumicis* that there are other winter hosts.
(2) w.v.—winged viviparous female; a.v.—apterous viviparous female.

Experimental evidence indicates that the sequence of winged and apterous agamic females is largely due to some internal inherent tendency. w.v. tend to produce a.v. and a.v. may produce entirely a.v. or a mixed progeny, consisting of a variable percentage of winged forms. The apterous condition is to be regarded as an adaptation, over a long period of time, to seasonal food and temperature conditions.

The appearance of sexual forms in the experiments—especially having regard to the cytological investigations in Aphids—shows that the change from the viviparous parthenogenetic phase to the sexual phase is doubtless associated with the chromozome complex, and not primarily due to food and temperature changes.

The agamic generations appear to be interpolated between the winter egg and the sexual generations as an adaptation to seasonal conditions.

Certain a.v. may produce agamic forms as well as sexual forms. In some cultures which were kept in a greenhouse, a.v. and *sexuparæ alatæ* (mothers of the oviparous females) developed in every generation throughout winter from September to April.

The degree of infestation for different species of plants varies considerably. Thus, experimenting with several plants of the same kind, the maximum total number of aphids produced from one a.v. over a 14-day period, for each kind of plant, is shown in the table below :—

Kind of Plant	Total number of aphids in 14 days.	
	1914 Germany	1920 Rothamsted
Broad Beans . . .	1192	1290
Field Beans . . .	1259	—
Sugar Beet . . .	696	294
Red Beet . . .	546	197
Mangolds	534	201
Peas	200	—
Rumex	252	—
Poppies	243	193

The higher figures obtained in Germany on Sugar Beet, Red Beet and Mangolds, suggests a local adaptation of the species to these food plants. Owing to other factors however, especially temperature, it is difficult to draw fine conclusions from any two series of experiments not carried out under the same experimental conditions.

The relative susceptibility of different varieties of Broad Beans was tested in 1920. Ten varieties were taken and 5 plants of each variety were infected with one a.v.

The average numbers of aphids produced from one a.v. on the 5 plants of each variety over a 14-day period were :—

No. of Variety.	1	2	3	4	5	6	7	8	9	10
Average No. of aphids.	897	1018	813	925	840	858	777	1099	746	1000

The results show that the infestation is slightly less on some varieties than on others. These varieties are, however, too closely related racially, to give striking differences, and the experiments are being continued with other varieties of Beans.

Further investigations are in hand dealing with the effect of the manurial treatment of crops on the degree of the infestation of plants by aphids; the relations between the varying constitution of the cell sap of plants, the food of aphids, and the infestation of plants by them, and the working of the stylets in relation to the cells of plant tissues.

XXXII. W. B. Brierley. "*Some Concepts in Mycology—an attempt at Synthesis.*" Trans. British Mycological Society, 1919. Vol. VI. (part ii.). 204-235.

The paper is divided into two parts which, however, are mutually dependent—the species concept and the concept of the educability of fungi. In the former the thesis is maintained that the morphological characters of an organism are a function of the particular genotype and the environmental conditions, and that the phenotypes of different organisms converge or diverge in constant and definite relation to the physico-chemical factors of the environment. Thus morphological characters are no true criterion of specificity. It is further maintained that the only exact method of species creation and specific determination is by means of quantitative physiological data derived from pure cultural treatment under standardised physico-chemical conditions. In the second part the thesis is put forward that the genotypes of "pure lines" of bacteria and fungi are constant and ineducable, and that genotype changes which have been described are better interpreted in terms of modification, of the selection of strains from a population, of stages in a complex life-cycle, or of segregation from a genetically impure ancestor.

XXXIII. W. B. Brierley. "*On a Form of Botrytis cinerea, with Colourless Sclerotia.*" Phil. Trans. Royal Society of London, 1920. Series B. Vol. 210. 83-114.

The fungus, *Botrytis cinerea,* produces black sclerotia, but in a single spore pedigree culture a colourless sclerotium was formed, which gave rise to a strain having colourless sclerotia. This character proved to be constant. The origin and relationships of this new strain are examined and a comparison made of the morphology and physiology of the colourless derivative with the parent. It is shown that the only apparent character in which the two strains differ is in the absence of pigment in the sclerotial skin.

The nature of the loss of colour is considered in relation to the biochemistry and genetics of albinism. The significance of the colourless form is discussed and the hypothesis brought forward that this and other genotypic changes among fungi are better interpreted in terms of segregation from a genetically impure parent than as true mutations. The possibilities of genetic contamination in sexual and asexual fungi are considered.

XXXIV. W. B. Brierley. "*Orchid Spot Disease.*" Gardeners' Chronicle, 1919. Vol. LXV. No. 1676.

A consideration of the several diseases of orchid leaves included under the name "Orchid Spot"; with notes on methods of treatment.

XXXV. J. Henderson Smith. "*The Killing of Botrytis Spores by Phenol.*" Annals of Applied Biology, 1921. Vol. VIII. No. 1.

It is shown that if *Botrytis* spores be exposed to the action of 0.4 per cent. phenol, the spores do not all die simultaneously, but some die in a few minutes and some not till two or three hours have elapsed. The curve showing the numbers surviving at different times has a sigmoid shape. If the strength of phenol be progressively raised, the curve becomes less and less sigmoid, approaching the logarithmic type of curve. With the same suspension it is possible to obtain either a logarithmic or a sigmoid curve according to the strength of phenol used. Both types of curve are shown to be explicable on the assumption that the individual spores differ in resistance and that a frequency curve showing the distribution in the resistance grades approaches the normal curve. The influence of the number of spores used is shown to be very considerable; and the consecutive transition from the sigmoid to the logarithmic type occurs, whether we raise the phenol strength, keeping the spore number constant, or reduce the spore number keeping the phenol constant, or use younger and younger spores.

TECHNICAL PAPERS.

CROPS AND CROP PRODUCTION.

XXXVI. Winifred E. Brenchley. "*Useful Farm Weeds.*" Journal of Board of Agriculture, 1918. Vol. XXV. pp. 949-958.

During the war the deficiency in supplies of every kind led to a revival of interest in the uses to which many farm weeds can be applied. If the need ever became sufficiently urgent, weeds might serve many useful purposes, but with the restoration of more normal conditions most of them have again fallen into disuse.

Weeds have their uses in medicine, as dyes, manures, and as fibre plants, but in times of stress they are most valuable as fodder and human food. Couch grass, spurry, bent grass, nettles, chicory, gorse and poppy cake can all serve as fodder, especially as most of them, in addition to being nutritious, are obtainable in large quantities.

Chicory and "salep" *(Orchis mascula)* are the principal weeds used as human food. Chicory has long been employed as a substitute or adulterant for coffee, while salep enters largely into the diet of people of Turkey, Persia and Syria. Many weeds provide leaves that have been used as substitutes for tea and coffee, and the young tops of nettles, garlic and dandelion have been frequently used as green vegetables by country folk.

XXXVII. WINIFRED E. BRENCHLEY. "*Eradication of Weeds by Sprays and Manures.*" Journal of Board of Agriculture, 1919. Vol. XXV. pp. 1474-1482.

The chemical substances used as weed killers may be divided into two groups :—

1.—Chemicals that merely destroy the weeds and have no direct beneficial action upon the growth of the crops. These substances are usually applied in the liquid form as sprays.

2.—Compounds that not only destroy the weeds but also exercise a manurial action, thus directly benefiting the crop at a later date. These substances are usually very finely ground manures and are applied as dry powders when the leaves are damp.

1.—*Sprays.* Most of these are corrosive in nature and destroy the delicate plant tissues, either killing the weeds outright or so crippling them that they cease to be active competitors with the crop. The chemicals are applied in solution, the strength varying according to circumstances. The most commonly used sprays are copper sulphate, iron sulphate, and sulphuric acid, but other substances are occasionally employed, including nickel sulphate, arsenite of soda, potassium chloride and sodium hydrogen sulphate.

Copper sulphate is effective in eradicating charlock, and is also useful against spurry and poppies. Iron sulphate destroys charlock, but is better than copper sulphate for eradicating poppies and corn buttercup. Sulphuric acid is one of the few sprays that has been found to clear grass land of bracken.

2.—*Manures.* During the last few years attempts have been made to destroy weeds on arable land by the application of finely ground manures, especially cyanamide and kainit, and on grass land by the use of lime, gas-lime and salt, and a fair measure of success is considered to have rewarded the effort. Calcium cyanamide and kainit have been used in eradicating charlock and other weeds, but the results are somewhat variable. Salt is occasionally useful in reducing weeds, especially on grass land, and lime also acts beneficially by making the soil less suitable for some of the worst pests on sour land, as spurry, sheep's sorrel, corn marigold and annual knawel.

Taking all things into consideration, the use of finely ground manures as weed killers offers possibilities, but up to the present the results have been so uncertain and variable that it is not yet advisable to make definite recommendations for their use.

XXXVIII. E. J. RUSSELL. "*Report on the proposed Electrolytic Treatment of Seeds* (Wolfryn process) *before Sowing.*" Journal of the Ministry of Agriculture, 1920. Vol. XXVI. pp. 971-981.

A discussion of the results of pot experiments made to ascertain whether the proposed electrolytic treatment of seed was effective in increasing crop production. In certain cases, increases in yield seemed to be obtained, but in the main the treatment cannot be relied upon to give a successful result : twice, or possibly three times, out of seven it apparently succeeded; once it apparently did harm, and in the remaining cases it did no good.

XXXIX. E. J. RUSSELL. "*The Composition of Potatoes immune from Wart Disease.*" Journal of the Ministry of Agriculture, 1920. Vol. XXVII. pp. 49-51.

An examination of 32 immune varieties of potatoes grown in 1919 and forwarded by the Glamorgan County Council. A general comparison only can be made with non-immune varieties, but the figures for dry matter and nitrogen content are of the same order as found at Rothamsted for the ordinary varieties of the country. There is nothing to suggest that the value to the purchaser would be any less, or that the supply of food would be adversely affected if immune varieties were substituted for non-immune.

FERTILISERS.

XL. E. J. RUSSELL. "*Report on the possibility of using Nitre-cake in the Manufacture of Super-phosphate.*" Ministry of Munitions, 1918.

An investigation to ascertain the conditions under which nitre-cake could be used as a substitute for sulphuric acid in the manufacture of super-phosphate, and the extent to which the replacement would be possible (see p. 26).

XLI. R. A. BERRY, G. W. ROBINSON and E. J. RUSSELL. "*Bracken as a Source of Potash.*" Journal of the Board of Agriculture, 1918. Vol. XXV. pp. 1-11.

During the war a search was made for possible sources of potash, and bracken ash seemed distinctly promising. Analyses were therefore made of samples obtained from various parts of the country, from which it is concluded that an acre of bracken cut in July or August—the best months for the purpose—might yield from 60 to 290lb. potash (K_2O) per acre according to locality, Ayrshire giving the best results.

XLII. E. J. RUSSELL. "*The Use of Ammonium Nitrate as Fertiliser.*" Journal of the Board of Agriculture, 1919. Vol. XXV. pp. 1332-1339.

The cessation of hostilities enabled the Ministry of Munitions to liberate large quantities of Ammonium Nitrate for fertiliser purposes, and as this possibility had been foreseen, experiments had been put in hand for some time previously. Ammonium Nitrate was found to be highly effective as a fertiliser, but to suffer from two defects :—It tends to attract water from the air (although this tendency can be diminished by suitable factory treatment), and it then sets to a solid which is not easily broken up; and it cannot be sent out in bags, but must travel in barrels, which is always an expensive mode of transit. Its great value is as a top dressing, for which it is particularly well suited, being probably the most rapid nitrogenous fertiliser known.

XLIII. E. J. RUSSELL. "*Synthetic Nitrogen Fertilisers.*" Journal of the Ministry of Agriculture, 1921. Vol. XXVII. pp. 1037-1045.

An account of the following fertilisers now being produced in various factories from the nitrogen of the air :—Nitrate of lime, nitrate of ammonia, ammonium carbonate, ammonium chloride, urea, cyanamide or nitrolim.

XLIV. G. A. Cowie. "*Decomposition of Cyanamide and Dicyanodiamide in the Soil.*" Journal of Agricultural Science, 1919. Vol. IX. pp. 113-136.

In field practice calcium cyanamide, commonly known in this country as nitrolim, has varied considerably in effectiveness. On the average of all field trials in the United Kingdom, when the effect of nitrate of soda is taken as 100, that of sulphate of ammonia is 97 and of cyanamide 90. But the cyanamide results fall as low as 26 and rise as high as 238. It is now shown that cyanamide under certain conditions contains another substance, dicyanodiamide, which is poisonous not only to plants but to the nitrifying organisms also. It is less toxic towards other bacteria, however, and has little effect on the numbers developing on gelatine plates, or on the rate and extent of the decomposition of dried blood. Nor does it reduce the rate of production of ammonia from cyanamide. In its presence ammonia accumulates in the soil, and the normal oxidation to nitrate does not take place.

Dicyanodiamide, therefore, not only injures the plant but cuts off the supply of nitrate, substituting instead ammonia, which in most cases is less useful, and in some cases directly harmful to the crop. The conditions under which it is formed are known and, fortunately, it can be avoided.

XLV. E. J. Russell. "*Farmyard Manure : its Making and its Use.*" Journal of the Farmers' Club, 1920. 89-106; also in Journal of the Ministry of Agriculture, 1920. Vol. XXVII. pp. 444-449.

A summary specially prepared for farmers of the results of the recent Rothamsted experiments with farmyard manure (see Report 1915-17 for details).

XLVI. E. J. Russell. "*The Influence of Farmyard Manure on the Clover Crop.*" Journal of the Board of Agriculture, 1919. Vol. XXVI. pp. 124-130.

Remarkably few field experiments have been made with the clover crop, but a series recently begun at Rothamsted indicate an unexpected effect on farmyard manure in increasing the yield. Where artificials had been applied to the preceding crops the yield was 19½ cwt. per acre, but where farmyard manure was used it was 32-35 cwt. No explanation can be offered with certainty, but the problem is under investigation in the laboratory.

XLVII. E. J. Russell. "*The Agricultural Value of Organic Manures.*" Journal of the Board of Agriculture, 1919. Vol. XXVI. pp. 228-247.

When Peruvian guano, rape cake and shoddy are compared on the basis of equal amounts of nitrogen per acre :—

Peruvian guano proved the most effective, especially in the year of application.

Rape cake came next.

Shoddy by a small margin came last in its year of application.

Numerically, the values were :—

Peruvian guano . . .	100
Rape cake	91
Shoddy	88

Shoddy showed a residual effect which would improve its position. The differences are less than might have been expected. No evidence could be obtained that the nitrogen in rape cake is superior in crop-producing power to the nitrogen of sulphate of ammonia or nitrate of soda. No larger crops were obtained from rape cake than from an equivalent of sulphate of ammonia and superphosphate, and actually less was obtained than from nitrate of soda.

There is very little evidence for the view that rape cake and Peruvian guano permanently benefit the soil. Where very large dressings of rape cake (10 cwt. to 1 ton per acre) are applied year after year to the same land there is, in course of time, an accumulation of nitrogen, but this proves of little value to wheat or barley; on the other hand, it may be more useful to mangolds, though the evidence is not conclusive.

In ordinary farm practice, where smaller dressings are given and less frequently than every year, there is little reason to anticipate any residual effect.

If this were the whole case there would be no reason why rape cake and guano should ever sell at prices above those obtaining for sulphate of ammonia or nitrate of soda. Yet farmers and manure makers have always been willing to pay more. There appear to be three reasons for this preference. Rape cake and guano are safer than artificial manures in the hands of inexperienced cultivators. No one would be likely to apply too much owing to high prices, and there is no necessity to mix with other fertilisers.

Further, from the manure makers' point of view, these substances have the enormous advantage of improving the condition of compound fertilisers, a property to which farmers rightly attach great importance in view of the widespread use of manure drills.

Lastly, from the special point of view of the horticulturist, who uses in the aggregate large quantities of manure, rape cake and guano, have the advantage that they can be applied once for all, whilst artificials would have to be given in several small doses, otherwise they might injure the soil.

XLVIII. W. E. Brenchley and E. H. Richards. "*The Fertilising Value of Sewage Sludges.*" Journal of the Society of Chemical Industry, 1920. Vol. XXXIX. pp. 177-182.

The sewage sludges produced by the old methods of tank treatment have very little fertilising value. Two new processes yield sludges of a different class. Slate-bed sludge and activated sludge are aerobically produced while the old precipitation and septic-tank sludges are essentially anaerobic. This difference accounts for the marked increase in manurial value of the newer sludges. The most valuable constituent is nitrogen. The average content in the old sludges tested by the Sewage Commission at Rothamsted and elsewhere, was 1.22%. Harpenden slate-bed sludge contains 2.63% and Withington activated sludge 7.09% of nitrogen; the availability of the nitrogen being 26% in the former and 66% in the latter.

Pot culture experiments made with the two sludges and an equivalent dressing of nitrate of soda showed that activated sludge gave a rather higher yield with the first crop of barley than the equivalent of nitrate of soda; slate-bed sludge came a long way behind, but still gave an increase of 22% over the unmanured pots. With the second crop of mustard, activated sludge showed a considerable residual value, while the slate-bed sludge was exhausted. Activated sludge is a fertiliser of great promise, but certain difficulties in drying it must be overcome before its value can be fully realised.

XLIX. H. B. Hutchinson and E. H. Richards. "*The Utilisation of Straw and the Production of Artificial Farmyard Manure.*" Journal of the Ministry of Agriculture, 1921.

The large increase in arable area brought about by the war at one time seemed likely to result in a glut of straw which could not be profitably utilised in agriculture or industry. Experiments have been going on at Rothamsted for some time with the view to making a nitrogenous and humus-forming manure from straw by bacterial decomposition alone. The nitrogen compounds in straw are inert and play little part in the rotting action of the manure heap. A considerable proportion of the carbohydrate material, however, is easily decomposed. This available starch and pentosan may be used to fix atmospheric nitrogen, and under ideal conditions the amount so gained may double the original nitrogen content of the straw. The cellulose and ligno-cellulose are not decomposed, so that the straw retains its tubular character and in no way resembles well rotted manure, even after prolonged storage. Pot-culture experiments and field trials showed that straw treated in this way possessed little fertilising value. In most cases the depressing action of raw straw on a crop sown at the time of application was merely reduced or eliminated, while under the best conditions the increase of crop over the unmanured soil was very small.

The conditions necessary to secure thorough rotting of straw were then investigated. The more important were found to be :—

1.—*Air supply.* Typical rotting occurs only under aerobic conditions. If air is excluded the straw remains unchanged for six months at least.

2.—*Supply of soluble nitrogen compounds in suitable concentration.* The concentration of even the weakest undiluted urine is above the maximum limit for decomposition. No rotting occurs until the concentration of ammonium carbonate has been sufficiently reduced by volatilisation.

3.—*Temperature.* The most rapid changes occur at about 35° C.

If soluble nitrogen compounds are supplied at the rate of 0.72 parts nitrogen per 100 parts of dry straw, all the added nitrogen is converted from a soluble to an insoluble organic form. Rotting will proceed until about 50 per cent. of the dry matter has been lost. Little or no loss of nitrogen occurs, so that the final product contains about 2.0 per cent. calculated on the dry matter. If soluble nitrogen compounds are added in excess of the limit, loss takes place until the concentration is reduced to the necessary extent when the action proceeds normally.

The new facts brought out by this investigation have several economic applications, some of which have already proved successful under prolonged practical tests. The more important are :—

1.—The production of an artificial farmyard manure.

2.—The recovery of soluble nitrogen from sewage.

3.—The prevention of waste in the usual process of manure making when the beasts are heavily fed with cake.

L. E. J. Russell. "*The Utilisation of Basic Slag.*" Trans. Faraday Society, 1920. Vol. XVI. pp. 263-271.

A discussion of the present position of the basic slag problem (see p. 16).

SOILS.

LI. E. J. Russell. "*Soil Making.*" Journal of the Royal Horticultural Society, 1919. Vol. XLIV. pp. 1-12.

A summary of the process concerned in soil making, with special reference to the means whereby, and the extent to which, the productiveness of devastated areas could be restored.

LII. E. J. Russell. "*The Tractor at Rothamsted.*" Modern Farming, 1920. Vol. IV. No. 6, October.

An account of eighteen months' experience on the Rothamsted farm (see p. 10).

LIII. and LIV. E. J. Russell. "*The Reclamation of Waste Land.*" Journal of the Royal Agricultural Society, 1919. Vol. LXXX. pp. 133-144.

"*The Improvement of Peaty Soils.*" I.—"*The True Peats.*" Journal of the Ministry of Agriculture, 1921. Vol. XXVII. pp. 1104-1113. II.—"*The Silty and Sandy Peats.*" Journal of the Ministry of Agriculture, 1921. Vol. XXVIII. pp. 32-35.

During the past ten years the author has made many examinations of waste soils with a view of devising methods of improvement. The analytical and agricultural results are set out here, and the causes of success and failure are discussed.

The waste lands of the Eastern half of England are mainly light sands or gravels, or thin chalk soils, suffering from defective water supply; while in the Western half they are commonly peats or stony clays, suffering from excess of water, lack of lime, and in case of high districts, from low temperature. To some extent remedial measures are possible.

LV. E. J. Russell. "*The Partial Sterilisation of Soils.*" Journal of the Royal Horticultural Society, 1920. Vol. XLV. pp. 237-256.

It has already been shown that steam and certain poisons are effective in ridding the soil of some of its insect and fungoid pests besides enhancing its fertility.

A more systematic investigation of the problem has now become possible through the recognition that poisons are, more or less, specific in their effects and may be less harmful to some organisms than to others.

The method of procedure is to analyse the soil population by examination of the plant or of the soil and so to determine what organism or organisms it is desired to suppress. An investigation is then made of the effect of a typical poison (*e.g.*, carbolic acid) on the organism; derivatives are systematically prepared, and the more toxic are followed up. In this way it has been possible greatly to intensify some of the soil sterilisers previously suggested for horticultural use; *e.g.*, carbolic acid becomes three to five times more effective by chlorination.

(Note.—This work is carried out by the W. B. Randall assistant, and full details for nurserymen are published in the Reports of the Nursery and Market Garden Experiment Station, Cheshunt, Herts.)

GENERAL AGRICULTURAL PROBLEMS.

LVI. E. J. Russell. "*British Crop Production.*" Royal Institution Discourses, Feb. 20th, 1920: Nature, 1920. Vol. CV. pp. 176 and 206.

LVII. E. J. Russell. "*The Possibility of Increased Crop Production.*" (Life and its Maintenance: Blackie & Son).

LVIII. E. J. Russell. "*Problems for Research after the War.*" Conference on the improvement of Agriculture. Trans. High. Society, 1918. Series 5. Vol. XXX. pp. 207-214.

LIX. E. J. Russell. "*Regional Factors in Agricultural.*" Geographical Teacher, 1920. No. 56.

LX. E. J. Russell. "*How the Soil was Made.*" Proc. Armstrong College of Agriculture, Students' Assoc., 1917-18. Vol. III. pp. 27-30.

LXI. E. J. Russell. "*Work of the Rothamsted Experimental Station.*' Journal of the Ministry of Agriculture, 1919. Vol. XXVI. pp. 497-507.

BOOKS.

ROTHAMSTED MONOGRAPHS ON AGRICULTURAL SCIENCE.

E. J. Russell. "*Soil Conditions and Plant Growth.*" 4th Edn. (entirely re-cast). Longmans, Green & Co., 1921.

Note.—A French translation by M. Georges Matisse is published in the Bibliothèque de culture generale (Flammarion, Paris). A German translation by Dr. Hans Brehm is published by Steinkopff (Berlin and Dresden). A translation into Finnish is being arranged.

Others in preparation dealing with :—

Soil Physics. B. A. Keen.
Soil Protozoa D. W. Cutler and L. M. Crump.
Soil Bacteria. H. G. Thornton.
Soil Fungi and Algæ. W. B. Brierley, S. T. Jewson and B. M. Bristol.

Winifred E. Brenchley. "*Weeds of Farm Land.*" Longmans, Green & Co., 1920. 41 Illustrations.

The book deals with the weed problem from both the practical and scientific standpoints. Attention is directed to the habits and characteristics of farm weeds, the methods of distribution, prevention and eradication, to the importance of the vitality of seeds when buried in the soil and to parasitic and poisonous weeds.

Separate chapters are devoted to the weeds of grass land and of arable land, and in the latter case the association of the weeds with various types of soil and crop is discussed. The uses of farm weeds and the popular and local names of the plants are collected together for the purpose of reference.

"*The Rothamsted Memoirs on Agricultural Science.*"

The more important of the papers issued from Rothamsted are bound up periodically into volumes and sold from the laboratory. The following are now available :—

Vols. 1-8 .	1847-1912 .	30/- postage extra
,, 9-10 .	1909-20 .	32/6 ,, ,,

CROP RESULTS.

SEASON, OCTOBER, 1917—SEPTEMBER, 1918.

The season that ended September 30th, 1917, had been bad for hay and corn, though favourable for roots and potatoes. There had been a drought through May and June, followed by a wet July and an unusually wet August, which greatly protracted the harvest. Fortunately, however, the weather improved in September and part of October, so that the land was in good condition for ploughing, and by dint of hiring extra teams, including two "Government" teams, we were able to overtake some of the arrears of work. November was exceptionally mild, but dull and fine, and by the 22nd the oats in Great Knott Field were well up, and the Broadbalk wheat was beginning to appear; the crops were much more forward than in the previous year. December was frosty and without snow, and the frost held over Christmas and the New Year; snow fell on January 16th but did not last; by February 18th the wheat, oats and clover had suffered, some of the plants had been killed and the survivors lacked vigour. Early in March the weather turned very cold, but afterwards it was wonderfully fine, and by the 20th the ground was dry and in beautiful condition for seeding and cleaning, so that hand-hoeing was done both in Broadbalk and in Long Hoos, where grass was growing among the wheat. The corn and clover all began to improve. On Sunday, March 24th, 1918, at 2 a.m., the clocks were put forward an hour to "summer time." In 1916 and 1917 the farm workers had declined to observe the change and continued to work by sun time, but this year they decided to adopt it now and henceforward. After the beginning of April the dry period was over; the barley and seeds mixture were safely in, but the potato land was not ready. On April 20th and 21st there fell snow and much rain, so that there was a great deal of water on the land and the Broadbalk drains were all running. February and March had been drier than the average, but April made up the deficit. Wireworm appeared in Long Hoos wheat and some eelworm in the Great Knott oats.

May was very fine. The winter oats were short in straw and rather backward. The grass also was short. On the other hand, the wheat was looking well, especially in Little Hoos after clover. Long Hoos wheat also looked much better than last year : there was some charlock in the west end, otherwise the field was tolerably clean. The root land was still not prepared by the end of May. June was dry, with sunny days but cold nights;. the pastures and meadows seemed unusually thick with buttercups and dandelions, perhaps because the grass was so short; later on thistles gave trouble : temporary grass, on the other hand, was longer and the clover was excellent. The drought continued till July 9th, ruining the new sown seeds and also the swedes (which were finally finished off by the " fly "), and making barley very short. On the other hand, the wheat was long in straw (5ft.) so also were the oats. King Edward potatoes suffered. Turnips were sown after the swedes, but failed.

At the end of July, Harpenden Field was ploughed by Government tractor and cleaned in preparation for oats. August was beautifully fine, hot and dry, and the harvest came in in record time. Much of the wheat was never stooked but was carried as it lay : some farmers indeed cut and carted on the same day, but we preferred not. September was wetter (4.8in.) and while this improved the mangolds it interfered with the lifting of the potatoes.

The harvest returns showed that wheat had been unusually good (5 qrs. per acre Red Standard; 4 qrs. Red Marvel). Potatoes had been only moderate (5 tons), mangolds poor and swedes failed.

OCTOBER, 1918—SEPTEMBER, 1919.

On September 29th no less than 1.3in. of rain fell, and this, coming at the end of a spell of wet weather, left the ground very wet. Rain fell almost daily in October and November, although the total was below the average. Its persistence, however, and shortage of labour interfered with ploughing, but, owing to the early harvest, work was fairly forward : by the time the Armistice was signed (Nov. 11th) oats and the first sown wheat were well up. Throughout November and December the weather continued mild and muggy, and the carting of mangolds was wet, dirty work. January was wet, impeding alike the ploughing and threshing; on the 28th came snow, which lay 9½ inches on the ground and then froze : the weather remained cold for some time. Then followed much rain till March 7th. The winter corn suffered and came out a bad colour after the snow, and the wheat contained some grass; clover, however, was looking well. Long Hoos had been intended for roots, being weedy, but owing to labour shortage half was put into barley, and our acreage of potatoes was cut down from 13 to 4.

There were frequent frosts in April and on the 29th a snow storm with 11in. of snow in the open; this, however, soon went. May was a magnificently fine month, with long sunny days and good dews at night; the total rainfall was only 0.46in. The hot weather continued till the end of June, parching the meadows and greatly retarding the potatoes. Currants, gooseberries and peas were full of blossom. Oats and early sown wheat and Stackyard barley looked well, but the late sown wheat and New Zealand barley were thin and full of thistles. Long Hoos barley was also weedy. July was a bad month; it was very cold and sunless and towards the end the corn showed signs of lodging, although there was no great length of straw. The local term for the condition of the wheat and barley was "scrawly," *i.e.*, many individual straws lodged, though the bulk stood: this is a common result of thin or uneven growth. The winter oats only were actually "lodged." The roots showed signs of picking up, but the second cut of clover was disappointing. The early part of August was hot; harvest began well, and although crops were light they were quickly brought in on our farm (though many others were less fortunate). Having now our own tractor, we pushed on well with the ploughing immediately the corn was cut; by September 8th we had ploughed Harpenden, Sawpit, Foster's, West Barnfield and part of Broadbalk fields. August and September were delightful months. A spell of wet weather lasting from August 25th to Sept. 5th rather delayed the carting, but it facilitated cultivation, cleaning and early sowing. Owing to the spring drought much of the seeds failed: only the clover sown in spring wheat in Great Knott Field survived. This was a great season for Daddy Longlegs. The differences on the experimental mangold plots showed up very well this year, though the yields were distinctly poor. When the corn was threshed out the yields were not unsatisfactory. Many farmers in the locality estimated their yields at 20 bush. of wheat, 22 of barley and 26 of oats only; ours were 34 bush. of wheat in two cases, but 20 only in the third. Oats, following clover, yielded 62 bushels. Potatoes improved considerably during the later part of the season, but finally yielded only 5½ tons per acre. Taking it altogether the season was a bad one and it ended badly: hay and roots had both proved disappointing.

OCTOBER, 1919—SEPTEMBER, 1920.

This season began in the extraordinary position that much of the ploughing was already nearly completed, consequently cross-ploughing and cultivations were carried out. The weather was remarkably suitable for cultivations: throughout October it was sunny by day and frosty by night, and the rainfall was only 1.0in. instead of 3.2in., the average. During the war years the fields had become foul: during this autumn we did much cleaning. On October 20th, Great Harpenden was drilled easily in spite of the drought: on October 23rd, New Zealand was drilled, but with more difficulty, the clods being not well broken. On October 24th, however, rain came, Stackyard and Broadbalk were, therefore, drilled easily. The oats in Sawpit were looking well, but nothing was yet showing in West Barnfield. By October 31st we had sown all our winter corn, excepting only 8 acres after mangolds and roots not yet lifted. The autumn tints were remarkably fine: this was popularly attributed to the dryness. November was very cold: the first snow came on the 11th.

In spite of the early sowing the wheat was late in starting, and it did not show in Harpenden Field till November 24th, a month after seeding: New Zealand, Stackyard and Broadbalk were not yet showing. December was milder and wet (5.3in. instead of 2.5in.), and it was not till the 18th that the bullocks were taken in: January was somewhat mild, the winter corn had strengthened considerably but was not too forward; February was also mild and March had some very warm days. February was very dry (0.5in. of rain only) : during March we had mild and growing weather. The wheat and oats looked well, having completely overcome the November check ; and the grass kept growing. The arable land remained free from weeds. Long Hoos barley was drilled on February 23rd, this being the earliest date for many years. April was wet and windy and unpleasant, but not cold. May was cold and dry ; the terrible flood that devastated Louth was represented here by a slight shower that barely wetted the soil. Oats made poor growth in Sawpit, except under the shelter of the plantation on the east side, and the hay was poor : wheat, however, looked well—indeed it was the best looking crop of the year, especially in Stackyard, New Zealand and Harpenden Fields : on Broadbalk, however, it was not so good, and there were many poppies, especially on the incompletely fertilised plots where the wheat had suffered during the spring ; oats were lengthening in the straw. July opened well, and the prospects for the season seemed very bright. Then, however, there set in a disastrous change ; after the first four days it became cold, wet, sunless and generally execrable to farmers. The position now altered very much for the worse. Fortunately, the seeds hay had been got in, but the permanent grass was still uncut. August was wintry and towards the end of the month we only just escaped frost ; the rainfall was low (1.2in.) but heavy downpours on the 2nd and 18th were harmful. A cold, sunless July always has a bad effect on our wheat crops, and this was no exception : good farmers had estimated at the beginning of July the yields on New Zealand at 48 bush., Harpenden at 46, and Stackyard at 44 bush. When we threshed out, the yields were only 40, 32 and 39 bushels respectively. Further, the oats were badly laid, although the yield was only 40 bushels. Fortunately, the harvest was got in easily and by the end of August practically all the corn and the second cuts of hay were in and a good beginning had been made with the ploughing. The mangolds had made good progress. The new clover was well established in Great Knott (west end) and on West Barnfield, and a strip of Long Hoos sown by the drill, whilst the part sown by the barrow (a usual practice on the farm in the past) was poor. Owing to the weedy condition of the last year's clover on Great Knott (east end), no second cut had been taken but the land ploughed in July and sown with mustard : this grew well and was ploughed in in September in preparation for oats. Mangolds in Barnfield and swedes in Little Hoos looked well : potatoes on Long Hoos, however, showed some disease and went off before the middle of September ; when lifted in October they were a fair crop (5 tons) clean, but with many small tubers. A sunless July is as bad for potatoes as it is for wheat.

The season began well but ended execrably. The yield of corn was disappointing, leaving the farm in an unfavourable financial condition. Only the grass flourished, and after the first cut it continued growing in a way that promised much winter keep

DATES OF SOWING AND HARVESTING (Harvest of 1918).

Field.	Crop.	Variety.	Sowing began.	Sowing finished.	Cutting began	Carting began.	Carting finished.	Yield per Acre.
Great Knott Wood, east	Oats	Grey Winter	Oct. 24, '17	Oct. 27, '17	Aug. 1	Aug. 15	Aug. 17	37 bush.
,, ,, west	,, ...	,, ...	,, ,,	,, ,,		,,	,,	
Little Knott Wood ...	Wheat	Red Standard (6 acres) ...	Nov. 8, '17	Nov. 8, '17	Aug. 10	Aug. 18	Aug. 18	40·5 ,,
		Red Marvel (7 acres)	Nov. 28, '17	Dec. 1, '17	,,	Aug. 27	Aug. 27	33 ,,
Fosters, east	Barley	Plumage Archer	Apr. 4, '18	Apr. 10, '18	Sept. 7	Sept. 11	Sept. 12	28 ,,
,, west	,, ...							
West Barnfield	Potatoes	Arran Chief and King Edward	May 3, '18	May 11, '18	Nov. 7	... ...	... ...	5 tons* ware & 5 cwts. chats
Long Hoos, east ...	Wheat	Red Standard	Nov. 6, '17	Nov. 23, '17	Aug. 17	Aug. 24	Aug. 30	40·5 bush.
,, west ...	,, ...							
Great Harpenden ...	Clover	Red	May 8, '17	May 8, '17	June 20	June 27	June 27	1·5 tons†
New Zealand	Swedes	Magnum Bonum and Early White	June 11, '18	June 11, '18	Failed	... ...	... ...	... ...
Stackyard	Mangolds ...	Yellow Globe	May 28, '18	May 28, '18	Nov. 18	... ...	... ...	12·3 tons
Sawpit	Wheat	Red Marvel (6 acres)	Nov. 30, '17	Nov. 30, '17	Aug. 16	Aug. 24	Aug. 24	33 bush.
Broadbalk	,, ...	Red Standard	Oct. 31, '17	Nov. 1, '17	Aug. 12	Aug. 20	Aug. 21	see p. 74
Little Hoos	,, ...	,, ...	Nov. 3, '17	Nov. 5, '17	Aug. 12	Aug. 20	Aug. 21	,, 77
Hoos	Barley	Plumage Archer	Mar. 18, '18	Mar. 18, '18	Sept. 2	Sept. 7	Sept. 9	,, 76
Barnfield	Mangolds ...	Sutton's Yellow Globe ...	Apr. 27, '18	Apr. 27, '18	Nov. 7	... ...	... ...	,, 69
Agdell	Clover	Red 1st Crop	May 14, '17	May 14, '17	June 22	July 2	July 2	,, 67
,, ...	,, ...	,, 2nd Crop	,,	,,	Aug. 31	Sept. 3	Sept. 3	,, 67
Greatfield	Grass	Rented out for Grazing ...						
Park	,, ...	1st Crop	... ...	... ...	June 24	July 3	July 4	see p. 70
		2nd Crop	... ...	... ...	Sept. 16	Sept. 24	Sept. 25	,, 70

NOTE.—7 acres of Sawpit were fallow. * Quantity sold after clamping, see pp. 79 and 82. † Estimated always on measurements, not weighed.

DATES OF SOWING AND HARVESTING (Harvest of 1919).

Field.	Crop.	Variety.	Sowing began.	Sowing finished.	Cutting began.	Carting began.	Carting finished.	Yield per Acre.
Great Knott Wood, east	Wheat	Red Standard	Nov. 26, '18	Nov. 26, '18	Aug. 23	Sept. 8	Sept. 8	20 bush.
		Red Marvel	Mar. 25, '19	Mar. 25, '19	Sept. 18	Oct. 1	Oct. 1	(see p. 83)
,, ,, west	,, ...	Red Standard	Nov. 9, '18	Nov. 9, '18	Aug. 22	Sept. 5	Sept. 5	
Little Knott Wood ...	Grass and Clover Ley ...	Red Clover, Alsike, Timothy, Cocksfoot and Bent ... 1st Crop	Apr. 8, '18	Apr. 8, '18	June 12	June 17	June 17	1 ton
		2nd Crop	,, ,,	,, ,,	Aug. 15	Aug. 18	Aug. 18	12 cwt.
Foster's, east	,, ...	,, ,, ,,	May 10, '18	May 10, '18	June 21	June 26	June 30	1 ton
,, west	,, ...	,, ,, ,,	May 10, '18	,, ,,	June 21	June 26	June 30	16 cwt.
West Barnfield	Wheat	Red Standard	Nov. 19, '18	Nov. 25, '18	Aug. 21	Sept. 1	Sept. 1	35 bush.
Long Hoos, east ...	Barley	Plumage Archer	Apr. 18, '19	Apr. 18, '19	Sept. 8	Sept. 17	Sept. 17	28 bush.
,, west ...	Mangolds ...	Sutton's Prize Winner, Yellow Globe	May 27, '19	May 27, '19	Oct. 19	... ...	... ...	9¼ tons
	Turnips	Sutton's Aberdeen Green Top Turnip	June 21, '19	June 21, '19	Oct. 28	... ...	... ...	
	Potatoes ...	King Edward and Arran Chief	May 20, '19	May 20, '19	Oct. 16	... ...	... ...	5½ tons
Great Harpenden ...	Oats	Grey Winter	Oct. 3, '18	Oct. 3, '18	July 31	Aug. 12	Aug. 14	62 bush.
New Zealand	Barley	Plumage Archer	Apr. 11, '19	Apr. 17, '19	Sept. 2	Sept. 11	Sept. 16	36 bush.
Stackyard	,, ...	,, ,, ,,	Apr. 9, '19	Apr. 9, '19	Sept. 1	Sept. 8	Sept. 8	32 bush.
Sawpit	Wheat	Red Standard	Oct. 16, '18	Oct. 23, '18	Aug. 15	Aug. 23	Aug. 27	34 bush.
Broadbalk	,, ...	,, ...	Oct. 25, '18	Oct. 26, '18	Aug. 14	Sept. 2	Sept. 5	see p. 74
Little Hoos	Barley	Plumage Archer	May 6, '19	May 6, '19	Sept. 11	Sept. 22	Sept. 22	,, 77
Hoos	,, ...	,, ...	Apr. 8, '19	Apr. 8, '19	Sept. 9	Sept. 16	Sept. 16	,, 76
Barnfield	Mangolds ...	Sutton's Yellow Globe ...	May 14, '19	May 14, '19	Oct. 29	... ...	... ...	,, 69
Agdell	Wheat	Red Standard	Oct. 18, '18	Oct. 18, '18	Aug. 11	Sept. 5	Sept. 5	,, 67
Greatfield	Grass	Rented out for Grazing ...						
Park	,, ...	1st Crop	... ...	... ...	June 16	June 18	June 18	,, 70
		2nd Crop	... ...	... ...	Sept. 23	Sept. 29	Sept. 30	,, 70

DATES OF SOWING AND HARVESTING (Harvest of 1920).

Field.	Crop.	Variety.	Sowing began.	Sowing finished.	Cutting began.	Carting began.	Carting finished.	Yield per Acre.
Great Knott Wood, east	Clover	Red	May 7, '19	May 7, '19	June 25	July 16	July 16	¾ tons
,, ,, west	Barley	Plumage Archer	Mar. 31, '20	Mar. 31, '20	Aug. 20	Aug. 30	Aug. 30	37 bush.
Little Knott Wood ...	Grass and Clover Ley ...	Red Clover, Alsike, Timothy, Cocksfoot and Bent ... 1st Crop	Apr. 8, '18	Apr. 8, '18	June 11	June 25	June 25	1½ tons
		2nd Crop	,, ,,	,, ,,	Sept. 2	Sept. 10	Sept. 10	
Foster's, east	Wheat	Yeoman	Sept. 25,'19	Sept. 25,'19	Aug 9	Aug. 21	Aug. 21	22 bush.
,, west	Grass and Clover Ley ...	Red Clover, Alsike, Timothy, Cocksfoot and Bent ...	May 10, '18	May 10, '18	June 28	July 14	July 14	1¾ tons
West Barnfield	Oats	Grey Winters	Oct. 3, '19	Oct. 3, '19	Aug. 9	Aug. 17	Aug. 23	*40 bush.
Long Hoos, east ...	Potatoes	Arran Chief	May 13, '20	May 22, '20	Oct 25	... ...	... ...	4 tons 1 cwt.
,, west ...	Barley	Plumage Archer	Feb. 23, '20	Feb. 27, '20	Aug. 13	Aug. 26	Aug. 28	36 bush.
	Wheat	Yeoman	Oct. 17, '19	Oct. 17, '19	Aug. 10	Aug. 21	Aug. 26	32 bush.
New Zealand	,, ...	Red Standard	Oct. 22, '19	Oct. 22, '19	Aug. 11	Aug. 25	Aug. 25	40 bush.
Great Harpenden ...	,, ...	Red Standard	Oct. 18, '19	Oct. 18, '19	Aug. 10	Aug. 23	Aug. 23	32 bush.
Stackyard	,, ...	Red Standard	Oct. 27, '19	Oct. 27, '19	Aug. 12	Aug. 26	Aug. 26	39 bush.
Sawpit	Oats	Grey Winters	Sept. 29,'19	Oct. 2, '19	Aug. 2	Aug. 16	Aug. 17	*40 bush.
Broadbalk	Wheat	Red Standard	Oct. 24, '19	Oct. 25, '19	Aug. 16	Aug. 28	Aug. 31	see p. 74
Little Hoos	Swedes	Sutton's Magnum Bonum ...	May 18, '20	May 19, '20	Oct. 19	... ...	... ...	,, 77
Hoos	Barley	Plumage Archer	Mar. 1, '20	Mar. 1, '20	Aug. 14	Aug. 27	Aug. 27	,, 76
Barnfield	Mangolds ...	Sutton's Yellow Globe ...	Apr. 29, '20	Apr. 29, '20	Dec. 5	... ...	... ...	,, 69
Agdell	Swedes	Sutton's Magnum Bonum ...	June 14, '20	June 14, '20	Oct. 19	... ...	... ...	,, 67
Greatfield, north ...	Grass	— —	... ...	... ...	July 19	Aug. 4	Aug. 18	,, 81
,, south ...	,, ...	— —	... ...	... ...	Aug. 17	Aug. 31	Sept. 9	,, 81
Park	,, ...	1st Crop	... ...	... ...	June 22	June 25	June 26	,, 70
		2nd Crop	... ...	... ...	Sept. 10	Sept. 27	Sept. 28	,, 70

* Sawpit and West Barnfield produce not kept separate this year.

CROP YIELDS ON THE EXPERIMENTAL PLOTS.

NOTE.—In each case the year refers to the harvest, *e.g.*, Wheat harvested in 1920

1 acre ... ... =	0·404 Hectare		0·963 Feddan
1 bushel (Imperial) =	0·346 Hectolitre (36·346 litres) ...		0·184 Ardeb
1 lb. (pound avoirdupois) =	0·453 Kilogramme		1·009 Rotls.
1 cwt. (hundredweight) =	50·8 Kilogrammes		113·0 Rotls. 1·366 Maunds
1 metric quintal ... =	100·0 Kilogrammes ... ... 220·46 lb.		
1 bushel per acre ... =	0·9 Hectolitre per Hectare ...		0·191 Ardeb per Feddan.
1 lb. per acre ... =	1·12 Kilogramme per Hectare ...		1·049 Rotls per Feddan.
1 cwt. per acre ... =	125·6 Kilogrammes per Hectare or 1·256 metric Quintals per Hectare		117·4 Rotls per Feddan.

In America the Winchester bushel is used = 35·236 litres. 1 English bushel = 1·032 American bushels.

Crops Grown in Rotation. Agdell Field.

PRODUCE PER ACRE.

Year.	CROP.		O. Unmanured		M. Mineral Manure.		C. Complete Mineral and Nitrogenous Manure.	
			5.	6.	3.	4.	1.	2.
			Fallow.	Beans or Clover.	Fallow.	Beans or Clover.	Fallow.	Beans or Clover.
EIGHTEENTH COURSE, 1916-19.								
1916	Roots (Swedes)	cwt.	12·4	1·4	125·2	145·2	285·2	37·8*
1917	Barley Grain	bush.	9·4	2·5	14·2	15·2	13·1	15·0
	Barley Straw ...	cwt.	11·6	5·1	16·8	15·6	13·1	19·8
1918	Clover Hay ... (1st and 2nd crops)	cwt.	—	19·5	—	59·5	—	17·0
1919	Wheat Grain	bush.	8·0	3·4	13·5	7·9	17·5	2·2
	Wheat Straw ...	cwt.	14·2	7·4	19·0	17·5	17·2	2·3
PRESENT COURSE (19th), 1920.								
1920	Roots (Swedes)	cwt.	20·4	2·2	163·8	270·0	262·2	56·4*

In 1920 Rape Cake was omitted from Plots 1 and 2.
* In 1916 and 1920, the roots on Plot 2 were badly attacked by finger and toe disease.

RAIN AND DRAINAGE.
MONTHLY MEAN FOR 50 YEARS, 1870—1920.

	Rainfall.	Drainage.			Drainage % of Rainfall.			Evaporation.		
		20-in. Gauge	40-in. Gauge	60-in. Gauge	20-in. Gauge	40-in. Gauge	60-in. Gauge	20-in. Gauge	40-in. Gauge	60-in. Gauge
	Ins.	Ins.	Ins.	Ins.				Ins.	Ins.	Ins
September	2·330	0·754	0·717	0·657	32·4	30·8	28·2	1·576	1·613	1·673
October ...	3·233	1·848	1·798	1·669	57·2	55·6	51·6	1·385	1·435	1·564
November	2·795	2·132	2·169	2·047	76·3	77·6	73·2	0·663	0·626	0·748
December	2·869	2·437	2·527	2·414	84·9	88·1	84·1	0·432	0·342	0·455
January...	2·364	1·892	2·078	2·001	80·0	87·9	84·6	0·472	0·286	0·363
February	2·008	1·480	1·584	1·513	73·7	78·9	75·4	0·528	0·424	0·495
March ...	2·103	1·148	1·285	1·215	54·6	61·1	57·8	0·955	0·818	0·888
April ...	2·012	0·653	0·727	0·695	32·5	36·1	34·5	1·359	1·285	1·317
May ...	2·025	0·475	0·537	0·502	23·5	26·5	24·8	1·550	1·488	1·523
June ...	2·375	0·595	0·616	0·595	25·1	25·9	25·0	1·780	1·759	1·780
July ...	2·667	0·680	0·703	0·654	25·5	26·4	24·5	1·987	1·964	2·013
August ...	2·719	0·740	0·741	0·697	27·2	27·3	25·6	1·979	1·978	2·022
Year ...	29·500	14·834	15·482	14·659	50·3	52·5	49·7	14·666	14·018	14·841

All four gauges measure $\frac{1}{1000}$ acre. Drain gauge records start Sept. 1st, 1870. Rain gauge records start Feb., 1853. For purpose of comparison the above figures deal with the same period as the drain gauge records, viz., Sept. 1st, 1870, to Aug. 31st, 1920.

METEOROLOGICAL RECORDS, 1918-20

	Rain.			Drainage through soil.			Bright Sunshine.	Temperature. (Mean)			
	Total Fall.		No. of Rainy Days. (0·01 inch or more)								
	5-inch Funnel Gauge.	1/1000 Acre Gauge.	1/1000 Acre Gauge.	20 ins. deep.	40 ins. deep.	60 ins. deep.		Max.	Min.	1 ft. in ground.	Solar Max.
1918	Inches.	Inches.	No.	Inches.	Inches.	Inches.	Hours.	°F.	°F.	°F.	°F.
Jan. ...	2·314	2·990	15	2·951	3·059	*3·045	57·2	42·6	31·4	37·5	71·7
Feb. ...	1·027	1·232	15	0·537	0·553	0·526	66·3	46·9	36·6	40·8	78·2
Mar. ...	0·861	0·985	8	0·024	0·078	0·073	141·4	49·9	33·2	40·5	94·1
April ...	3·946	4·548	17	3·481	3·537	3·294	97·2	48·8	36·5	43·1	91·4
May ...	2·258	2·471	10	0·487	0·633	0·640	207·5	63·5	45·1	52·3	116·9
June ...	0·862	0·998	12	0·003	0·024	0·027	226·5	64·3	45·5	57·1	123·4
July ...	3·215	3·447	18	0·654	0·698	0·620	200·4	68·0	51·6	60·0	124·5
Aug. ...	1·163	1·331	11	0·004	0·032	0·040	178·9	68·9	52·9	61·4	122·9
Sept. ...	4·974	5·421	24	2·293	2·181	2·044	155·3	60·0	47·6	55·8	111·8
Oct. ...	1·703	1·964	15	1·094	1.140	1·065	78·8	53·5	41·9	49·6	88·1
Nov. ...	2·518	2·674	17	2·165	2·064	1·947	70·8	47·4	35·3	43·9	75·1
Dec. ...	2·839	3·175	26	2·814	2·897	2·754	36·5	48·7	39·8	44·3	65·1
Total or Mean	27·680	31·236	188	16·507	16·896	16·075	1516·8	55·2	41·5	48·9	96·9
1919											
Jan. ...	3·840	4·281	25	2·964	3·079	2·980	32·7	40·3	31·5	38·3	60·9
Feb. ...	2·901	3·290	14	3·975	3·961	3·925	48·1	38·7	27·9	35·3	73·1
Mar. ...	3·432	3·747	19	2·796	2·871	2·801	107·3	43·9	33·2	38·7	88·0
April ...	3·311	3·693	16	1·970	2·034	2·020	120·4	51·3	36·2	43·1	106·0
May ...	0·460	0·535	5	0·208	0·359	0·370	257·7	65·1	45·1	52·7	119·0
June ...	1·045	1·159	7	—	0·009	0·018	230·7	66·6	47·6	59·6	124·3
July ...	2·625	2·767	15	0·330	0·394	0·379	120·1	63·0	49·0	57·7	114·2
Aug. ...	3·239	3·404	12	1·337	1·389	1·346	228·9	70·3	52·2	61·4	124·1
Sept. ...	1·191	1·293	10	0·076	0·118	0·093	158·3	63·4	47·1	57·2	112·2
Oct. ...	0·977	1·073	14	No drainage this month			136·2	51·4	36·5	46·7	93·5
Nov. ...	2·049	2·239	20	1·569	1·331	1·238	48·6	41·4	32·4	40·5	67·4
Dec. ...	5·048	5·573	24	5·717	5·836	5·801	33·4	46·1	35·3	40·0	63·2
Total or Mean	30·118	33·054	181	20·942	21·381	20·971	1522·4	53·5	39·5	47·6	95·5
1920											
Jan. ...	2·730	3·015	21	2·548	2·620	2·590	51·0	45·7	34·3	39·6	66·5
Feb. ...	0·432	0·511	10	0·044	0·136	0·108	84·2	48·1	34·8	40·2	79·9
Mar. ...	1·403	1·629	17	0·399	0·405	0·407	141·4	52·3	36·4	42·5	98·6
April ...	4·246	4·585	20	3·167	3·183	3·163	90·3	52·3	40·8	47·1	100·8
May ...	1·208	1·336	13	0·009	0·064	0·061	241·6	61·1	45·1	52·7	118·9
June ...	1·832	1·927	12	0·045	0·079	0·098	233·5	65·6	48·8	59·0	124·9
July ...	4·613	4·780	20	2·036	2·060	1·983	148·2	64·3	50·2	59·4	120·0
Aug. ...	1·256	1·363	8	0·148	0·230	0·211	150·7	63·0	48·8	58·1	118·4
Sept. ...	1·961	2·131	13	0·417	0·388	0·368	110·5	62·9	48·1	55·8	109·3
Oct. ...	1·427	1·530	10	0·592	0·666	0·618	144·8	57·7	42·2	51·9	99·7
Nov. ...	1·687	1·846	9	1·365	1·206	1·129	71·8	48·2	35·3	43·4	77·4
Dec. ...	2·288	2·545	25	2·244	2·362	2·284	37·7	43·0	34·4	40·0	58·7
Total or Mean	25·083	27·198	178	13·014	13·399	13·020	1505·7	55·4	41·6	49·1	97·8

* On January 18 and 19, 1918, the cylinders and tank of 60″ gauge were submerged: the figures for the 40″ gauge are adopted (2·735″) and included in above total.

Mangolds, Barn Field, 1918, 1919, 1920.

Roots since 1856. Mangolds since 1876.
Produce per Acre.

Strip.	Strip Manures.	O. None.	N. Nitrate of Soda	A. Ammon. Salts.	A.C. Ammon. Salts and Rape Cake.	C. Rape Cake.
		Cross Dressings.				
		Tons.	Tons.	Tons.	Tons.	Tons.
	1918.					
1	Dung only	R. **17·98**	**33·79**	**25·39**	**24·45**	**24·48**
		L. 2·79	4·17	3·39	3·16	3·69
2	Dung, Super., Potash ...	R. **25·26**	**38·58**	**34·73**	**34·04**	**28·30**
		L. 3·11	4·63	4·45	5·02	3·88
4	Complete Minerals ...	R. **4·61**	R. **28·59** L. 3·15	**22·39**	**29·65**	**16·88**
		L. 0·82	R. **27·65** L. 3·34	2·03	3·63	[illegible]
5	Superphosphate only ...	R. **5·65**	**25·18**	**12·50**	**12·33**	**12·50**
		L. 0·93	2·49	2·56	2·11	1·79
6	Super. and Potash ...	R. **4·58**	**25·09**	**20·30**	**25·56**	**15·03**
		L. 0·86	2·45	1·83	2·94	1·46
7	Super., Sulphate of Mag., and Sodium Chloride	R. **4·71**	**28·81**	**23·94**	**25·01**	**17·21**
		L. 0·84	2·82	2·41	3·05	1·97
8	None	R. **3·18**	**19·92**	**11·05**	**10·32**	**9·76**
		L. 0·69	2·81	2·64	2·53	1·89
9	Sodium Chloride, Nit. Soda, Sulph. Potash, and Sulph. Mag. ...	R. **26·56**				
		L. 2·57				
	1919.					
1	Dung only	R. **9·05**	**17·49**	**14·14**	**10·60**	**11·28**
		L. 3·60	6·36	4·55	4·74	4·83
2	Dung, Super., Potash ...	R. **13·97**	**18·51**	**19·87**	**15·24**	**18·17**
		L. 5·67	8·89	8·23	7·60	6·92
4	Complete Minerals ...	R. **2·46**	R. **12·98** L. 6·55	**7·75**	**11·77**	**9·57**
		L. 0·97	R. **12·86** L. 5·69	4·43	6·86	3·48
5	Superphosphate only ...	R. **1·97**	**9·98**	**1·13**	**3·05**	**4·58**
		L. 0·81	4·38	1·00	1·86	1·88
6	Super. and Potash ...	R. **2·44**	**14·46**	**11·45**	**13·14**	**12·08**
		L. 0·91	5·81	4·54	5·98	2·84
7	Super., Sulphate of Mag., and Sodium Chloride	R. **3·13**	**15·93**	**14·48**	**14·98**	**13·94**
		L. 0·91	5·23	4·73	5·31	2·98
8	None	R. **2·16**	**7·63**	**3·08**	**4·06**	**6·50**
		L. 0·82	3·63	1·58	1·63	2·57
9	Sodium Chloride; Nit. Soda, Sulph. Potash and Sulph. Mag. ...	R. **20·38**				
		L. 5·14				
	1920.					
1	Dung only	R. **18·99**	**30·26**	**21·38**	**23·89**	**25·12**
		L. 3·51	4·27	3·95	4·62	5·31
2	Dung, Super., Potash ...	R. **26·84**	**37·69**	**33·11**	**32·67**	**28·73**
		L. 4·78	6·74	6·69	7·28	5·94
4	Complete Minerals ...	R. **4·54**	R. **26·10** L. 4·68	**20·81**	**26·35**	**12·39**
		L. 0·96	R. **21·21** L. 2·90	3·54	4·75	2·17
5	Superphosphate only ...	R. **4·82**	**20·73**	**7·72**	**8·31**	**8·48**
		L. 0·95	3·33	2·84	2·86	2·13
6	Super. and Potash ...	R. **4·65**	**21·50**	**18·94**	**24·74**	**9·89**
		L. 1·04	3·49	2·84	4·39	2·25
7	Super., Sulphate of Mag., and Sodium Chloride	R. **4·91**	**21·84**	**19·95**	**19·05**	**11·86**
		L. 1·28	3·27	3·08	4·13	2·41
8	None	R. **3·99**	**13·81**	**5·91**	**4·44**	**6·17**
		L. 0·82	2·69	2·19	1·92	2·04
9	Sodium Chloride; Nit. Soda; Sulph. Potash and Sulph. Mag. ...	R. **29·35**				
		L. 4·86				

R.=roots. L.=leaves.

Notes: 1918—All Potash, Magnesia, and Rape Cake omitted.

Hay. The Park Grass Plots. 1918, 1919, 1920.

Plot.	Manuring.		Yield of Hay per acre. 1918. 1st Crop.	2nd Crop.	Total.	Yield of Hay per acre. 1919. 1st Crop.	2nd Crop.	Total.	Yield of Hay per acre. 1920. 1st Crop.	2nd Crop.	Total.	Plot.
			cwts.	cwts.	cwts.	cwts.	cwts.	cwts.	cwts.	cwts.	cwts.	
1	Single dressing Amm. Salts (=43 lbs. N.); (with Dung 8 years, 1856-63)	not limed	9·8	8·3	17·1	10·0	7·8	17·8	23·8	10·2	34·0	1
		limed ...	17·2	7·6	24·8	10·4	8·5	18·9	24·3	7·8	32·1	
2	Unmanured; (after Dung 8 years, 1856-63)	not limed	16·5	3·5	20·0	6·4	4·2	10·6	17·5	5·2	22·7	2
		limed ...	16·0	2·5	18·5	6·4	2·0	8·4	19·2	5·5	24·7	
3	Unmanured	not limed	14·7	2·8	17·5	4·1	3·7	7·8	15·7	4·1	19·8	3
		limed ...	15·1	3·4	18·5	3·8	2·2	6·0	16·0	4·2	20·0	
4-1	Superphosphate of Lime	not limed	24·2	4·3	28·5	9·1	4·9	14·0	24·1	6·8	30·9	4-1
		limed ...	17·6	3·4	21·0	6·1	1·9	8·0	25·0	6·2	31·2	
4-2	Superphosphate of Lime and double dressing Amm. Salts (=86 lbs. N.)	not limed	18·5	5·0	23·5	9·4	1·9	11·3	25·6	5·2	30·8	4-2
		limed ...	26·3	10·5	36·8	17·4	9·0	26·4	31·4	10·0	41·4	
5-1	(N. half) Unmanured; following double dressing Amm. Salts (= 86 lbs. N.) 1856-97	not limed	12·1	2·8	14·9	4·4	3·8	8·2	10·3	5·4	15·7	5-1
5-2	(S. half) Super., Sulphate of Potash; following double dressing Amm. Salts (= 86 lbs. N.) 1856-97	not limed	24·5	5·8	30·3	13·0	7·3	20·3	20·8	8·8	29·6	5-2
6	Complete Mineral Manure as plot 7; following double dressing Amm. Salts (= 86 lbs. N.) 1856-68	not limed	41·5	7·9	49·4	23·0	13·1	36·1	35·3	14·8	50·1	6
7	Complete Mineral Manure	not limed	37·9	7·3	45·2	19·8	13·1	32·9	31·7	14·3	46·0	7
		limed ...	42·3	5·5	47·8	21·1	10·7	31·8	41·8	12·3	54·1	
8	Mineral Manure without Potash	not limed	21·7	4·2	25·9	9·9	9·8	19·7	19·9	7·4	27·3	8
		limed ...	19·3	4·2	23·5	8·8	6·8	15·6	16·4	7·2	23·6	
9	Complete Mineral Manure and double dressing Amm. Salts (= 86 lbs. N.)	not limed	32·5	14·2	46·7	36·5	16·7	53·2	34·3	15·3	49·6	9
		limed ...	46·7	12·8	59·5	50·6	17·1	67·7	42·3	13·1	55·4	
10	Mineral Manure (without Potash) and double dressing Amm. Salts (= 86 lbs. N.)	not limed	24·5	9·0	33·5	26·1	8·4	34·5	22·1	10·5	32·6	10
		limed ...	42·8	10·8	53·6	37·1	13·5	50·6	35·3	12·0	47·3	
11-1	Complete Mineral Manure and treble dressing Amm. Salts (=129 lbs. N.)	not limed	44·9	19·0	63·9	35·4	30·1	65·5	41·0	35·4	76·4	11-1
		limed ...	52·5	17·5	70·0	49·1	18·0	69·1	52·6	21·4	74·0	
11-2	As plot 11-1 and Silicate of Soda	not limed	48·0	23·3	71·3	51·8	26·9	78·7	50·9	33·4	84·3	11-2
		limed ...	49·0	18·6	67·6	57·6	21·5	79·1	52·1	28·1	80·2	

12	Unmanured	not limed	17·9	5·8	23·7	7·7	6·9	14·6	12·7	6·9	19·6	12
13	Dung in 1905, and every fourth year since (omitted in 1917) Fish Guano in 1907 and every fourth year since	not limed	41·2	13·4	54·6	45·0	15·9	60·9	34·0	14·4	48·4	13
		limed ...	37·8	10·9	48·7	35·1	15·0	50·1	34·2	11·6	45·8	
14	Complete Mineral Manure and double dressing Nitrate of Soda (=86 lbs. N.)	not limed	44·3	19·2	63·5	65·2	17·7	83·9	68·8	18·9	87·7	14
		limed (sun)	—	—	—		—	—	74·7	13·6	88·3	
		limed (shade)	—	—	—	—	—	—	53·5	34·7	88·2	
15	Complete Mineral Manure as plot 7; following double dressing Nitrate of Soda (= 86 lbs. N.) 1858-75	not limed	29·8	9·5	39·3	17·4	9·1	26·5	34·8	10·8	45·6	15
		limed ...	—	—	—	—	—	—	28·3	12·5	40·8	
16	Complete Mineral Manure and single dressing Nitrate of Soda (= 43 lbs. N.)	not limed	41·0	14·3	55·3	34·0	10·1	44·1	48·3	10·1	58·4	16
		limed ...	35·8	9·4	45·2	25·3	13·2	38·5	43·4	11·1	54·5	
17	Single dressing Nitrate of Soda (= 43 lbs. N.)	not limed	25·4	5·2	30·6	11·3	6·3	17·6	36·2	9·5	45·7	17
		limed ...	—		—	—	—	—	30·9	10·2	41·1	
18	Potash, Sulphate of Soda, Magnesia, and double dressing Sulphate of Amm. (= 86 lbs. N.) 1905 and since	not limed	29·0	12·7	41·7	24·9	13·5	38·4	25·1	24·5	49·6	18
		limed (6788 lbs.)	—		—	—	—	—	27·8	17·9	45·7	
		limed (3951 lbs.)	—	—					34·3	12·1	46·4	
19	Farmyard Dung in 1905 and every 4th year since (omitted in 1917)	not limed	32·7	6·8	39·5	16·4	11·3	27·7	29·6	14·7	44·3	19
		limed (3150 lbs.)	—	—	—	—	—	—	32·1	14·1	46·2	
		limed (570 lbs.)	—	—	—	—	—	—	31·3	12·0	43·3	
20	Farmyard Dung in 1905 and every 4th year since (omitted 1917); each intervening year, plot 20 receives Sulphate of Potash, Superphosphate and Nitrate of Soda (=26 lbs. N.)	not limed	41·9	8·9	50·8	27·6	12·3	39·9	39·2	13·4	52·6	20
		limed (2772 lbs.)	—		—	—			41·7	14·7	56·4	
		limed (570 lbs.)				—	—	—	44·5	11·3	55·8	

Ground lime was applied to the Southern portion (limed) of the plots at the rate of 2,000 lb. to the acre in the Winter of 1903, 1907, 1915, and at the rate of 2,500 lbs. to the acre in the Winter of 1920, except where otherwise stated.

In 1918 all Sulphate of Potash and Sulphate of Magnesia were omitted from the Mineral Manures in plots 6, 7, 9, 11-1, 11-2, 14, 15, 16, and 18; also Potash was omitted from plot 5-2, and Magnesia from plots 8 and 10.

1919, instead of Sulphate of Potash, an equivalent amount of Muriate of Potash was used.

In 1919 and 1920 an equivalent amount of Sulphate of Ammonia was used instead of Muriate of Ammonia.

Up to 1914 the limed and unlimed plot results were not separately given in the Annual Report, but the mean of the two was given. From 1915 onwards the separate figures are given.

In the reports for 1913, 1914, 1915-17 the manuring of plot 5-2 was incorrectly given as complete Mineral Manure, instead of as Superphosphate and Sulphate of Potash.

The Park Grass Plots.

BOTANICAL COMPOSITION, PER CENT.

Plot.	Manuring.	Liming.	Crop.	1918. Gramineæ.	1918. Leguminosæ.	1918. Other Orders.	1919. Gramineæ.	1919. Leguminosæ.	1919. Other Orders.	"Other Orders" consist largely of	Plot.
1	Single Amm. Salts, (with Dung 8 years, 1856-63)	Limed ...	1st	—	—	—	77·71	·68	21·62	Rumex acetosa and Centaurea nigra	1
		,, ...	2nd	—	—	—	82·66	·27	17·07		
1	,, ,, ...	Not limed	1st	—	—	—	86·36	—	13·65	Rumex acetosa	1
		,,	2nd	—	—	—	93·70	—	6·30		
2	Unmanured; (after Dung 8 years, 1856-63)	Limed ...	1st	—	—	—	61·13	5·65	33·22	Plantago lanceolata, Ranunculus spp., and Centaurea nigra	2
		,, ...	2nd	—	—	—	62·55	7·16	30·30		
2	,, ,, ...	Not limed	1st	—	—	—	57·94	4·38	37·68	Plantago lanceolata, Centaurea nigra, Conopodium denudatum	2
		,,	2nd	—	—	—	55·99	4·27	39·74		
3	Unmanured	Limed ...	1st	52·67	10·88	36·44	58·59	5·51	35·90	Plantago lanceolata and Centaurea nigra	3
		,, ...	2nd	50·00	7·16	42·84	50·80	7·89	41·31		
3	,, ...	Not limed	1st	45·04	6·30	48·65	47·62	4·55	47·82	Plantago lanceolata, Leontodon hispidus and Poterium sanguisorba ...	3
		,,	2nd	44·27	2·51	53·21	54·40	4·13	41·50		
4-1	Superphosphate of Lime	Limed ...	1st	41·30	10·82	47·90	53·63	9·66	36·71	Plantago lanceolata, Rumex acetosa, and Centaurea nigra	4-1
		,, ...	2nd	43·20	6·05	50·65	54·17	6·19	39·64		
4-1	,, ,, ...	Not limed	1st	49·17	3·48	47·35	52·77	2·76	44·47	Plantago lanceolata and Rumex acetosa	4-1
		,,	2nd	50·36	1·86	47·77	46·74	2·67	50·60		
4-2	Super. of Lime and double Amm. Salts	Limed ...	1st	96·51	—	3·48	98·17	—	1·82	Rumex acetosa	4-2
		,, ...	2nd	98·77	—	1·23	98·81	—	1·18		
4-2	,, ,, ...	Not limed	1st	88·94	·12	10·96	91·94	—	8·05	Rumex acetosa	4-2
		,,	2nd	96·96	·28	2·74	97·74	—	2·26		
5-1	Unmanured, following double Amm. Salts, 1856-97	Whole plot	1st	—	—	—	77·81	·39	21·80	Rumex acetosa and Centaurea nigra	5-1
		,,	2nd	—	—	—	67·70	1·98	30·31		
5-2	Super. and Sulph. Potash following double Amm. Salts, 1856-97 ...	Whole plot	1st	65·69	7·10	27·20	63·19	4·54	32·27	Rumex acetosa and Luzula campestris	5-2
		,,	2nd	57·31	8·87	33·82	60·33	12·22	27·46		
6	Complete Mineral Manure following double Amm. Salts, 1856-68 ...	Whole plot	1st	57·63	16·29	26·08	57·18	11·46	31·37	Rumex acetosa and Conopodium denudatum	6
		,,	2nd	70·78	4·32	24·90	69·01	13·48	17·52		
7	Complete Mineral Manure	Limed ...	1st	70·75	16·04	13·19	59·10	19·62	21·28	Rumex acetosa, Ranunculus spp. and Conopodium denudatum	7
		,, ...	2nd	74·30	13·68	12·03	62·62	25·23	12·15		
7	,, ,, ...	Not limed	1st	57·12	11·11	31·79	52·05	8·77	39·18	Rumex acetosa, Conopodium denudatum, and Achillea millefolium	7
		,,	2nd	58·33	5·20	36·46	56·32	18·61	25·08		
8	Mineral Manure (without Potash) ...	Limed ...	1st	55·29	6·23	38·50	58·46	7·51	34·02	Rumex acetosa and Plantago lanceolata	8
		,,	2nd	49·79	5·80	44·40	53·01	7·97	39·02		
8	,, ,, ,, ...	Not limed	1st	37·68	6·32	56·01	46·62	10·55	42·82	Plantago lanceolata and Rumex acetosa	8
		,,	2nd	34·88	7·49	57·63	52·03	9·19	38·77		

9	Complete Mineral Manure, and double Amm. Salts	Limed ...	1st	97·81	—	2·18	95·85	·09	4·05	Rumex acetosa	9
		,,	2nd	99·26	-	·73	98·40	·97	·61		
9	,, ,, ,, ...	Not limed	1st	79·91	—	20·10	85·00	—	15·00	Rumex acetosa	9
		,,	2nd	97·34	—	2·65	94·75	—	5·24		
10	Mineral Manure (without Potash) and double Amm. Salts	Limed ...	1st	99·68		·31	99·59		·41	Rumex acetosa	10
		,,	2nd	100·00	—	—	99·77	—	·23		
10	,, ,, ,, ...	Not limed	1st	87·86	—	12·13	92·60	—	7·40	Rumex acetosa	10
		,,	2nd	99·59	—	·41	97·36	-	2·63		
11-1	Complete Mineral Manure and treble Amm. Salts	Limed ...	1st	99·63	- -	·37	99·84		·16	Rumex acetosa	11-1
		,,	2nd	100·00	—	—	99·49	—	·52		
11-1	,, ,, ,, ...	Not limed	1st	97·50	—	2·50	98·86	—	1·14	Rumex acetosa	11-1
		,,	2nd	100·00	—	—	99·56	—	·43		
11-2	As plot 11-1 and Silicate of Soda ...	Limed ...	1st	99·59	·06	·35	100·00	—	—		11-2
		,,	2nd	100·00	—	—	99·86	—	·13		
11-2	,, ,, ,, ...	Not limed	1st	98·54	—	1·47	99·62	- -	·38	Rumex acetosa	11-2
		,,	2nd	99·82	—	·18	99·75	—	·25		
12	Unmanured	Whole plot	1st	—	-	—	54·80	5·34	39·87	Plantago lanceolata and Conopodium denudatum	12
		,,	2nd		—		50·56	8·19	41·24		
13	Dung in 1905 and every 4th year since (omitted in 1917); Fish Guano in 1907 and every 4th year since ...	Limed ...	1st	- -		—	86·89	·82	12·28	Rumex acetosa and Conopodium denudatum	13
		,,	2nd	—	—		92·12	2·51	5·37		
13		Not limed	1st	- -		—	79·83	·07	20·09	Rumex acetosa and Conopodium denudatum	13
		,,	2nd	—	—	—	96·23	·26	3·51		
14	Complete Mineral Manure and double Nitrate of Soda	Whole plot	1st	—	—	—	92·92	2·41	4·68	Anthriscus sylvestris	14
		,,	2nd	—			95·29	·74	3·97		
15	As plot 7, following double Nitrate of Soda, 1858-75	Whole plot	1st	75·32	6·99	17·70	69·25	5·39	25·35	Rumex acetosa and Achillea millefolium	15
		,,	2nd	73·26	3·15	23·58	77·14	6·54	16·31		
16	As plot 7, and single Nitrate of Soda	Limed ...	1st	—	—	—	89·60	·78	9·62	Anthriscus sylvestris	16
		,,	2nd	—	—	—	90·69	·89	8·42		
16	,, ,, ,, ...	Not limed	1st	—	—	—	85·98	1·17	12·84	Taraxacum vulgare and Plantago lanceolata	16
		,,	2nd	-	—	—	86·60	1·26	12·14		
17	Single Nitrate of Soda	Whole plot	1st	—	—	—	58·53	·43	41·04	Plantago lanceolata and Centaurea nigra	17
		,,	2nd	-	-	-	66·55	·24	33·21		
18	Potash, Sulph. Soda, Magnesia and double Sulph. Amm., 1905 and since	Whole plot	1st			-	68·93		31·07	Rumex acetosa and Conopodium denudatum	18
		,,	2nd				80·04		19·95		
19	Farmyard Dung, 1905, and every 4th year since (omitted in 1917) ...	Whole plot	1st	72·80	6·59	20·61	75·21	6·17	18·61	Rumex acetosa and Ranunculus spp.	19
		,,	2nd	83·97	7·54	8·50	83·43	9·34	7·22		
20	Dung in 1905 and every 4th year since (omitted in 1917). Each intervening year Sulph. Potash, Super. and Nitrate of Soda	Whole plot	1st	78·44	9·26	12·29	81·85	4·72	13·44	Rumex acetosa, Anthriscus sylvestris, Ranunculus spp.	20
		,,	2nd	88·10	4·29	7·61	91·93	4·13	3·94		

WHEAT. BROADBALK FIELD, 1918, 1919, 1920.

Manures.	1918. Top portion. Dressed Grain. Yield per Acre.	1918. Top portion. Dressed Grain. Weight per Bushel.	1918. Top portion. Straw per Acre.	1918. Bottom portion. Dressed Grain. Yield per Acre.	1918. Bottom portion. Dressed Grain. Weight per Bushel.	1918. Bottom portion. Straw per Acre.	1919. Top portion. Dressed Grain. Yield per Acre.	1919. Top portion. Dressed Grain. Weight per Bushel.	1919. Top portion. Straw per Acre.	1919. Bottom portion. Dressed Grain. Yield per Acre.	1919. Bottom portion. Dressed Grain. Weight per Bushel.	1919. Bottom portion. Straw per Acre.	1920. Top portion. Dressed Grain. Yield per Acre.	1920. Top portion. Dressed Grain. Weight per Bushel.	1920. Top portion. Straw per Acre.	1920. Bottom portion. Dressed Grain. Yield per Acre.	1920. Bottom portion. Dressed Grain. Weight per Bushel.	1920. Bottom portion. Straw per Acre.	Average for 61 years, 1852-1912. Dressed Grain per Acre.	Average for 61 years, 1852-1912. Straw per Acre.
	Bushels	lb.	cwt.	Bushels	lb.	cwt.	Bushels	lb.	cwt.	Bushels	lb.	cwt.	Bushels	lb.	cwt.	Bushels	lb.	cwt.	Bushels	cwt.
Farmyard Manure	30.8	65.3	38.8	36.1	65.1	39.9	22.8	62.7	19.0	27.1	62.3	21.6	28.3	61.5	38.4	33.2	62.0	42.6	35.2	34.8
Unmanured	11.5	64.1	9.9	10.0	64.6	9.1	9.2	61.0	7.0	9.8	60.4	7.4	9.4	61.0	8.8	8.1	60.9	7.8	12.6	10.3
Complete Mineral Manure ...	9.1	64.6	10.0	9.0	64.9	10.1	9.8	60.3	7.8	10.0	61.5	7.0	8.2	61.3	8.3	8.2	62.1	8.0	14.5	12.1
As 5, and Single Amm. Salts ...	16.5	64.8	23.5	13.2	64.9	15.4	19.5	61.1	15.7	18.4	61.6	13.9	15.3	61.5	16.1	15.1	61.2	14.9	23.2	21.4
As 5, and Double Amm. Salts	25.2	64.6	35.1	23.0	65.0	33.8	27.6	61.4	21.4	33.3	61.6	24.7	21.6	61.3	25.7	30.9	60.9	36.5	32.1	32.9
As 5, and Treble Amm. Salts	27.7	65.1	45.6	27.5	65.3	44.2	29.6	61.7	29.3	37.4	61.7	29.6	27.1	61.8	45.4	28.8	60.4	42.3	36.6	41.1
As 5, and Single Nitrate of Soda	21.5	64.9	30.7	21.6	65.4	25.9	21.0	60.2	17.5	23.9	61.0	18.8	23.6	61.1	25.7	26.8	61.6	27.4	—	—
Double Amm. Salts alone ...	13.8	64.5	16.9	15.9	64.7	18.8	16.4	59.8	13.6	15.2	58.9	13.1	15.7	59.5	19.0	13.0	60.0	18.0	20.0	18.4
As 10, and Superphosphate ...	17.9	64.5	21.7	16.5	64.7	21.1	10.7	57.6	16.1	12.4	57.0	15.7	13.6	59.7	19.1	9.6	58.9	21.5	22.9	22.3
As 10, and Super. and Sulph. Soda	20.8	64.6	25.8	24.3	63.9	27.4	17.3	58.2	16.2	18.5	57.8	19.9	19.3	60.3	27.9	18.4	60.8	28.1	29.1	28.0
As 10, and Super. and Sulph. Potash	20.3	65.0	27.2	22.9	64.7	31.6	29.3	60.6	25.9	27.4	60.8	24.8	24.9	61.4	29.6	28.9	61.1	39.0	31.0	31.5
As 10, and Super. and Sulph. Magnesia	21.4	64.9	24.2	24.8	64.7	32.1	17.7	58.3	19.2	27.5	59.3	23.6	15.5	59.8	26.1	18.2	59.7	28.8	28.8	28.0
Double Amm. Salts in Autumn and Minerals	25.9	65.0	33.0	22.3	65.1	31.5	22.5	60.3	18.3	20.7	60.4	15.8	17.6	61.1	24.3	16.1	61.1	23.0	29.9	29.7
Double Nitrate and Minerals...	29.7	65.4	41.8	25.4	65.5	41.6	32.8	60.9	29.6	32.6	61.3	29.7	25.2	61.4	30.8	25.5	61.2	35.0	—	—
Minerals alone, or double Amm.	17.5	65.0	20.3	21.8	65.1	28.8	11.7	62.9	8.1	13.8	62.4	9.4	19.1	61.3	19.6	20.0	61.5	21.1	29.9	29.5
Salts alone in alternate years	12.4	65.0	10.1	16.6	65.4	12.6	30.2	60.6	21.9	30.0	61.0	25.3	6.3	58.4	6.9	6.4	59.9	7.7	14.9	13.0
Rape Cake alone	17.0	65.0	13.7	15.4	64.9	16.8	13.5	61.5	9.5	12.0	61.6	11.2	11.8	60.3	10.9	13.0	60.4	14.3	*25.4	*25.7
Mineral Manure (without Super.) and Amm. Salts	17.3	65.3	19.8	—	—	—	21.7	61.5	18.6	—	—	—	15.4	59.6	18.7	—	—	—	—	—

* Average for 20 years, 1893-1912.

1918, 1919, Sulphate of Potash omitted from plots 5, 6, 7, 8, 9, 13, 15, 16, 17 or 18, 20. Sulphate of Soda omitted from plot 12. Sulphate of Magnesia omitted from plot 14.

1918, 1919, 1920. Rape Cake omitted from plot 19.

Plot 17 received Mineral dressing in 1919. Amm. Salts in 1918, 1920.

Plot 18 ,, ,, ,, 1918, 1920. ,, ,, 1919.

From 1917 onwards, Muriate of Ammonia has been replaced by an equivalent amount of Sulphate of Ammonia.

Hoos Field (formerly Potato Plots). **No Manure since 1901.**

Plot.	Manuring given prior to 1901.	1918. BARLEY.				1919. BARLEY.			
		Dressed Grain.		Straw per Acre.	Total Produce per Acre.	Dressed Grain.		Straw per Acre.	Total Produce per Acre.
		Yield per Acre.	Weight per Bush.			Yield per Acre.	Weight per Bush.		
	Previous Cropping: Potatoes, 1876-1901; Barley, 1902 and 1903; Oats, 1904; Barley, 1905-1911; Oats, 1912; Barley, 1913 and 1914; Oats, 1915; Barley, 1916-17.								
		Bush.	lb.	cwt.	lb.	Bush.	lb.	cwt.	lb.
1	Unmanured	8·4	52·4	4·0	912	4·7	52·3	3·2	645
2	Unmanured 1882 to 1901, previously Dung only	11·1	51·8	5·7	1243	7·5	53·1	4·6	964
3	Dung 1883 to 1901	16·2	54·8	8·6	1878	11·5	53·1	6·4	1379
4	Dung 1883 to 1901	16·3	53·1	7·5	1728	12·7	52·9	6·7	1475
	Previous Cropping: Potatoes, 1876-1901; Barley, 1902-1903; Oats, 1904; Plots 5, 7, 9, Cow Peas (failed), 1905; Plots 6, 8, 10, Red Clover, 1905; Red Clover, 1906-1911; Oats, 1912; Barley, 1913 and 1914; Oats, 1915; Barley, 1916-17.								
5	Ammonium Salts	11·6	54·5	7·0	1440	7·6	51·3	5·1	1004
6	Nitrate of Soda	15·8	54·1	7·6	1723	7·7	51·8	5·1	1014
7	Ammonium Salts and Mixed Minerals	21·0	54·1	11·1	2422	12·1	53·1	5·9	1339
8	Nitrate of Soda and Mixed Minerals ...	19·2	53·5	8·2	1973	9·3	53·0	5·5	1150
9	Superphosphate	14·4	54·1	7·6	1660	8·8	53·6	4·1	965
10	Mixed Minerals	14·8	53·4	6·7	1561	10·7	53·5	5·3	1278

NOTE.—In 1920 these plots were fallowed.

Permanent Barley Plots. Hoos Field, 1918, 1919, 1920.

PRODUCE PER ACRE

Plot.	MANURING.	1918			1919			1920			Average 60 years, 1852—1911.	
		Dressed Grain.	Weight per Bushel.	Straw.	Dressed Grain.	Weight per Bushel.	Straw.	Dressed Grain.	Weight per Bushel.	Straw.	Dressed Grain.	Straw.
		Bush.	lb.	cwt.	Bush.	lb.	cwt.	Bush.	lb.	cwt.	Bush.	cwt.
1 O	Unmanured	18·3	52·1	7·9	5·5	52·0	3·6	6·4	55·4	3·2	14·3	8·4
2 O	Superphosphate only	27·7	51·7	11·0	11·6	54·8	5·7	13·2	53·4	7·5	19·7	10·0
3 O	Alkali Salts only	16·9	51·7	7·9	9·0	54·4	5·8	9·1	52·9	4·7	15·2	8·8
4 O	Complete Minerals	24·9	52·2	11·5	14·6	54·1	8·4	13·7	52·6	6·3	19·7	11·1
5 O	Potash and Superphosphate	14·7	51·5	7·3	9·4	55·0	6·1	5·2	54·5	3·4		
1 A	Ammonium Salts only	25·1	50·7	11·5	11·2	52·5	6·5	17·3	51·2	8·1	25·5	14·7
2 A	Superphosphate and Amm. Salts	41·4	50·6	17·7	18·1	51·4	9·1	22·8	51·7	10·7	38·2	22·0
3 A	Alkali Salts and Amm. Salts	23·4	52·1	11·2	15·7	53·4	9·1	16·1	53·1	9·6	28·0	16·9
4 A	Complete Minerals and Amm. Salts	34·9	51·7	15·7	24·5	54·6	12·5	38·5	52·7	14·9	41·5	25·0
5 A	Potash, Super. and Amm. Salts	38·6	52·1	20·3	23·5	54·6	14·0	30·4	53·4	16·3		
1 AA	Nitrate of Soda only	26·7	51·3	14·7	16·1	53·3	9·7	20·2	53·3	12·1	29·3	17·8
2 AA	Super. and Nitrate of Soda	46·4	52·5	22·6	30·1	54·1	14·4	37·3	53·3	16·1	43·1	26·3
3 AA	Alkali Salts and Nitrate of Soda	21·1	52·0	13·3	16·7	54·1	11·3	14·7	53·1	12·3	30·0	19·3
4 AA	Complete Minerals and Nitrate of Soda	43·3	50·6	16·9	28·0	54·1	15·1	31·8	54·1	15·3	42·7	27·3
1 AAS	As Plot 1 AA and Silicate of Soda	29·2	51·6	14·5	20·3	54·0	12·9	27·7	53·8	14·8	32·8 (1)	19·7 (1)
2 AAS	,, ,, 2 AA ,, ,,	45·1	52·7	21·7	27·8	52·9	12·0	39·4	53·7	15·7	42·3 (1)	26·0 (1)
3 AAS	,, ,, 3 AA ,, ,,	24·0	52·7	16·1	19·8	54·0	12·6	23·9	52·8	15·8	35·2 (1)	21·7 (1)
4 AAS	,, ,, 4 AA ,, ,,	39·5	51·3	20·3	20·5	54·8	12·2	30·5	54·3	15·5	43·6 (1)	27·7 (1)
1 C	Rape Cake only	18·7	52·5	9·3	10·7	53·9	5·6	11·9	53·9	5·8	38·3	22·1
2 C	Superphosphate and Rape Cake	21·9	52·0	11·1	11·7	54·6	6·7	12·1	53·4	5·6	40·5	23·6
3 C	Alkali Salts and Rape Cake	16·6	51·3	9·2	8·5	54·5	5·3	9·7	54·0	4·8	36·9	22·3
4 C	Complete Minerals and Rape Cake	17·3	52·6	8·9	10·0	54·1	6·2	10·2	54·5	4·5	40·5	24·5
7—1	Unmanured (after dung 20 years, 1852—71)	26·7	52·4	12·0	12·1	54·5	6·5	17·5	53·6	8·0	24·8 (2)	14·8 (2)
7—2	Farmyard Manure	58·8	53·0	28·7	32·1	55·2	18·2	48·3	54·3	27·3	47·1	29·6
6—1	Unmanured	20·9	52·3	9·2	7·6	53·5	4·3	13·3	53·5	7·3		
6—2	Ashes from Laboratory Furnace	19·5	50·6	8·5	6·8	53·5	3·9	10·2	53·8	5·7		
1 N	Nitrate of Soda only	26·3	50·6	14·0	12·5	53·0	8·6	10·3	53·3	6·4		
2 N	,, ,, ,,	27·8	52·1	15·9	19·5	54·9	11·4	20·3	53·0	10·5		

(1) 48 years, 1864—1911. (2) 40 years, 1872—1911.

NOTES:—1918. Sulphate of Potash, Sulphate of Magnesia and Rape Cake omitted in all cases. 1919 and 1920. Rake Cake omitted in all cases. Also since 1917 Muriate of Ammonia replaced by equivalent amount of Sulphate of Ammonia.

Little Hoos Field

PLAN OF ROTATION PLOTS

Arranged to test the RESIDUAL VALUE of VARIOUS MANURES in one, two, three, and four years after their application. Produce per acre.

Plot.	Manure per Acre.	Year of Last Dressing.	1918 (15th Season). Wheat. Dress'd Grain Bush. per Acre.	Straw cwt. per Acre.	Total Pr'd'ce lb. per Acre.	1919 (16th Season). Barley. Dr'ss'd Grain Bush. per Acre.	Straw cwt. per Acre.	Total Pr'd'ce lb. per Acre.	1920 (17th Season). Swedes. Roots tons per Acre.	Leav's tons per Acre.	Total tons per Acre.
A 1	Control	—	*36·3*	*36·7*	*6613*	*10·8*	*8·7*	*1669*	*9·43*	*2·60*	*12·03*
2	Ordinary Dung, 16 tons	1920	42·5	45·7	8129	27·9	17·2	3554	**18·38**	**3·10**	**21·48**
3		1913	44·3	42·9	7924	27·4	16·1	3390	12·02	2·45	14·47
4		1914	43·2	42·8	7812	25·8	14·7	3128	10·43	2·17	12·60
5		1915	42·1	41·8	7685	29·3	18·0	3758	13·40	2·84	16·24
B 1	Cake fed dung, 16 tons	1920	44·8	46·3	8288	28·6	16·9	3519	**21·74**	**3·73**	**25·47**
2	Control	—	*38·2*	*36·7*	*6831*	*14·7*	*10·5*	*2075*	*8·42*	*2·32*	*10·74*
3	Cake fed dung, 16 tons	1913	46·8	47·3	8550	28·8	15·9	3462	15·20	3·00	18·20
4		1914	44·2	43·5	7974	29·8	16·7	3546	16·89	3·39	20·28
5		1915	44·6	44·0	8024	29·6	17·1	3553	14·80	2·88	17·68
C 1	Shoddy, 308 lb.; Super. 292 lb.; Sulph. of	1920	33·6	32·6	6071	11·4	9·0	1715	**11·93**	**3·62**	**15·55**
2	Potash 110 lb. ...	1913	32·9	32·9	6097	14·3	9·8	1985	10·54	3·58	14·12
3	Control	—	*36·5*	*33·5*	*6344*	*13·4*	*8·4*	*1756*	*13·66*	*3·65*	*17·31*
4	Shoddy 308 lb.; Super. 292 lb.; Sulph. of	1914	34·9	36·6	6635	17·2	10·5	2194	12·62	3·33	15·95
5	Potash 110 lb. ...	1919	37·5	37·2	6765	**23·3**	**14·5**	**2996**	14·57	3·50	18·07
D 1	Guano 352 lb.: Sulph. Amm. 44 lb. ...	1920	38·3	39·2	7119	14·9	10·0	1968	**14·44**	**4·25**	**18·69**
2	Sulph. of Potash 86 lb.	1913	34·8	31·8	6041	12·9	8·4	1735	12·71	3·47	16·18
3		1914	35·5	37·9	6839	17·1	10·4	2171	14·43	4·18	18·61
4	Control	—	*37·2*	*41·2*	*7258*	*13·6*	*8·6*	*1809*	*9·61*	*2·99*	*12·60*
5	Guano 352 lb.; Sulph. Amm. 44 lb.; Sulph. of Potash 86 lb. ...	1919	37·4	38·5	7004	**24·3**	**17·0**	**3412**	5·80	2·22	8·02
E 1	Rape Dust 844 lb.; Super. 240 lb. ...	1920	38·1	38·2	7003	13·7	9·5	1911	**13·33**	**4·14**	**17·47**
2	Sulph. of Potash 80 lb.	1913	37·1	40·3	7166	15·7	10·5	2162	14·05	3·13	17·18
3		1914	34·3	34·7	6309	14·5	8·7	1881	14·17	3·42	17·59
4		1919	34·4	37·3	6609	**22·4**	**13·5**	**2871**	10·90	2·78	13·68
5	Control	—	*39·3*	*39·5*	*7207*	*15·7*	*11·0*	*2161*	*6·43*	*2·31*	*8·74*
F 1	Control	—	*35·6*	*37·3*	*6703*	*10·8*	*8·4*	*1629*	*3·32*	*1·46*	*4·78*
2	Super. 292 lb.; Sulph.	1920	36·7	36·2	6675	12·3	8·9	1805	**16·30**	**3·46**	**19·76**
3	Amm. 196 lb.; Sulph.	1913	31·8	33·0	5995	11·7	8·1	1673	9·31	2·55	11·86
4	of Potash 110 lb. ...	1914	35·5	37·5	6751	12·4	8·2	1696	7·84	2·15	9·99
5		1919	36·1	37·7	6788	**23·9**	**16·3**	**3276**	9·23	2·75	11·98
G 1	Bone Meal 160 lb.; Super. 110 lb.; Sulph.	1920	34·9	33·9	6321	14·8	9·6	1952	**8·63**	**3·10**	**11·73**
2	Amm. 188 lb. ...	1913	33·0	32·7	6025	16·5	9·9	2060	6·27	2·01	8·28
3	Control	—	*34·6*	*35·2*	*6374*	*17·6*	*9·6*	*2118*	*3·60*	*1·11*	*4·71*
4	Bone Meal 160 lb.; Super. 110 lb.; Sulph.	1914	37·5	36·8	6714	16·9	10·2	2131	6·00	1·74	7·74
5	Amm. 188 lb. ...	1919	36·0	37·7	6780	**23·2**	**14·6**	**3022**	7·12	2·31	9·43
H 1	Basic Slag 520 lb.; Super. 110 lb.; Sulph.	1920	41·6	37·4	7016	24·4	13·3	2867	**15·77**	**3·58**	**19·35**
2	Amm. 196 lb. ...	1913	42·3	41·1	7485	24·0	13·0	2816	11·48	2·87	14·35
3		1914	39·6	40·6	7303	23·2	12·8	2741	11·48	2·85	14·33
4		1919	40·6	37·0	6934	**31·2**	**17·4**	**3750**	10·72	2·58	13·30
5	Control	—	*36·8*	*38·0*	*6837*	*19·8*	*11·3*	*2431*	*4·87*	*1·54*	*6·41*

NOTES AS TO MANURES.

In 1919 a new system of manuring was begun. The manure for each plot (except of series A and B) was rationed at 40 lbs. Nitrogen, 100 lbs. Calcium Phosphate, and 50 lbs. Potash per acre. Each plot was supplied with as much of its particular manure (shoddy, guano, &c.) as possible without exceeding the receipt in any of the three rationed ingredients. Any deficit in either of these three was then made good by adding the necessary quantity of Sulphate of Amm., Superphosphate, or Sulphate of Potash. Series A and B left as before.

No manure was applied in 1917 or 1918. For manures 1904-17 see Report for 1915-16-17.

Figures in italics denote unmanured plots. The yields on the plots to which the manure was applied in a given year are printed in heavy type.

RED CLOVER grown year after year on rich Garden Soil, Rothamsted Garden.

Hay, Dry Matter, and Nitrogen per Acre, 1913 to 1920.

Year.	No. of Cuttings.	As Hay.	Dry Matter.	Nitrogen.	Seed Sown.
		lbs.	lbs.	lbs.	
1913	2	4211	3509	98	1912, April, mended
1914	2	2041	1701	46	,, ,, ,,
1915	1	1304	1087	26	,, ,, ,,
1916	1	1724	1437	51	1916, April 21st, re-sown
1917	3	3351	2793	81	1917, April 23rd, mended
1918	2	2262	1885	50	1918, April 6th, re-sown
1919	2	898	748	22	1919, April 27th, mended
1920	3	4400	3667	114	1920, May 5th, mended
Averages:					
25 years, 1854—1878		7664	6387	179	
25 years, 1879—1903		3924	3270	101	
50 years, 1854—1903		5794	4829	140	
15 years, 1904—1918		2888	2407	70	

Wheat after Fallow (without Manure 1851, and since). Hoos Field, 1918, 1919, 1920.

	1918.	1919.	1920.	Average 61 years 1856-1916.
Dressed Grain { Yield—Bushels per Acre	15·3	11·8	9·4	15·6
Dressed Grain { Weight per Bushel—lbs.	61·7	59·9	62·8	59·5
Straw—cwt. per Acre	14·1	9·6	8·9	13·4
Total Produce—lbs. per Acre	2611	1848	1642	2477

DRESSED SEED EXPERIMENT, 1919.

Barley. Little Hoos Field.

Description of Plot.	Dressed Grain. Yield per Acre. Single Strength.	Dressed Grain. Yield per Acre. Double Strength.	Dressed Grain. Weight per Bushel. Single Strength.	Dressed Grain. Weight per Bushel. Double Strength.	Straw per Acre. Single Strength.	Straw per Acre. Double Strength.	Total Produce per Acre. Single Strength.	Total Produce per Acre. Double Strength.
	Bushels.	Bushels.	lbs.	lbs.	cwt.	cwt.	lbs.	lbs.
Heavy Oil ...	23·5	20·0	54·0	54·5	13·2	11·8	2880	2580
	24·3	—	54·3	—	14·1	—	3055	—
Bone Oil ...	19·3	17·5	54·5	54·0	11·6	10·4	2465	2235
	24·5	—	54·5	—	14·5	—	3110	—
Creosote ...	21·5	11·3	53·3	53·0	12·3	8·8	2695	1750
	22·6	—	53·0	—	14·1	—	2920	—
Acetone Tar	21·1	12·5	54·5	53·0	12·5	9·1	2695	1770
	19·9	—	52·5	—	12·9	—	2605	—
Gas Tar ...	23·0	14·1	53·0	54·0	13·2	7·9	2810	1743
	13·1	—	53·5	—	12·9	—	2260	—
Control ...	22·0	14·7	55·0	53·0	12·9	9·1	2810	1885
	18·9	—	54·0	—	10·0	—	2300	—
	23·7	—	54·0	—	13·8	—	2935	—
	18·4	—	54·5	—	11·8	—	2460	—

Single Strength represents 1 pint of dressing to 4 bushels of seed.

TOP DRESSING EXPERIMENT.

Oats (Grey Winter). Great Harpenden Field, 1919.

Manures per Acre.	Dressed Grain. Yield per Acre. 1st Expt.	2nd Expt.	3rd Expt.	Dressed Grain. Weight per Bushel. 1st Expt.	2nd Expt.	3rd Expt.	Straw per Acre. 1st Expt.	2nd Expt.	3rd Expt.	Total Produce per Acre. 1st Expt.	2nd Expt.	3rd Expt.
	Bush.	Bush.	Bush.	lbs.	lbs.	lbs.	cwt.	cwt.	cwt.	lbs.	lbs.	lbs.
Sulphate Amm. 1½ cwts., Super. 3 cwts. ...	79·9	62·6	62·3	42·0	42·8	41·8	40·4	34·2	32·4	8206	6850	6675
Nitrate Soda 2 cwts., Super. 3 cwts. ...	71·9	68·9	67·6	42·8	41·9	42·1	41·7	38·0	37·5	8169	7500	7284
Nitrate Amm. ¾ cwt., Super. 3 cwts. ...	74·1	68·9	57·4	42·5	42·4	44·0	37·7	34·4	32·6	7700	7119	6544
Nitrolim 2 cwts., Super. 3 cwts.	67·1	58·4	60·3	42·0	42·6	42·0	33·9	29·0	30·1	6900	6069	6706
Guandine Nitrate 84 lbs., Super. 3 cwts. ...	75·7	—	63·1	41·4	—	42·9	37·3	—	32·6	7547	—	6678
Guandine Sulphate 94 lbs., Super. 3 cwts. ...	73·3	56·7	53·0	41·3	45·0	43·5	32·4	27·7	27·0	6900	5972	5706
Guandine Carb. 75 lbs., Super. 3 cwts. ...	68·2	61·5	52·5	42·1	42·8	43·3	30·6	28·4	26·6	6638	6200	5547
Super 3 cwts.	64·1	49·0	—	42·0	42·9	—	30·4	25·5	—	6388	5269	—
Control	68·1	49·7	48·6	42·9	44·3	43·0	33·3	24·3	26·3	6981	5238	5444
	58·9	47·8	47·4	43·6	41·6	43·0	28·4	23·4	23·7	6056	4781	4975
	—	48·1	39·0	—	46·8	42·5	—	24·3	22·8	—	5256	4637

Wheat (Red Standard). Great Harpenden Field, 1920.

Date of Applying Dressing.	Dressed Grain. Yield per Acre. Single Dressing.	Double Dressing.	Dressed Grain. W'ght per Bush Single Dressing.	Double Dressing.	Straw per Acre. Single Dressing.	Double Dressing.	Total Produce per Acre. Single Dressing.	Double Dressing.
	Bush.	Bush.	lbs.	lbs.	cwt.	cwt.	lbs.	lbs.
Early: Feb. 10th	28·7	35·9	63·6	63·6	26·9	35·9	4960	6456
Medium: March 16th ...	29·8	—	63·8	—	31·1	—	5522	—
Late: May 10th	31·6	32·6	62·9	62·7	33·6	36·9	6020	6490
Control	28·9		63·9		24·2		4683	

Single dressing represents 100 lbs. Sulphate Amm. and 100 lbs Super.

SUBSOILING EXPERIMENT.

Potatoes (King Edward). West Barnfield, 1918.

Treatment of Plots.	Yield per Acre. East.	West.
	cwt.	cwt.
Subsoiled in 1914	75·1	127·3
Not Subsoiled	90·7	133·7

VARIETY EXPERIMENT.

Wheat. Great Harpenden Field, 1920.

Variety.	Dressed Grain. Yield per Acre.	Dressed Grain. Weig't per Bush	Straw per Acre.	Total Produce per Acre.
	Bushels.	lbs.	cwt.	lbs.
Red Standard	26·2	63·6	32·2	5475
Yeoman	27·0	63·3	29·7	5333
Fenman	28·6	62·8	34·3	5845

FLUE DUST EXPERIMENTS.

Mangolds. Stackyard Field, 1918.

Plot.	Manures per Acre.	Weight of Roots per Acre. Tons.	"Best Rows."[1] Number of Rows.	"Best Rows."[1] Weight per Acre. Tons.
10	Superphosphate 4 cwt., Salt 2 cwt. ...	16·7	8	19·6
12A		16·9	7	25·1
14		17·9	5	21·9
1	Superphosphate 4 cwt., Salt 2 cwt., Sulphate Ammonia 2 cwt.	19·3	5	26·8
9		17·9	9	20·9
11	Superphosphate 4 cwt., Salt 2 cwt., Nitrate Ammonia 145 lbs.	20·7	8	25·2
15		25·9	all	25·9
2	Super. 4 cwt., Salt 2 cwt., Sulphate Amm. 2 cwt., Flue Dust, grade 1, 3·1 cwt ...	14·2	4	22·2
3	Ditto, Flue Dust, grade 2, 7·5 cwt. ...	11·9	2	23·6
4	Ditto, Flue Dust, grade 3, 5 cwt.	15·5	4	21·4
5	Ditto, Extracted Flue Dust, 6·5 cwt. ...	19·9	all	19·9
6	Ditto, Sulphate of Potash, 1 cwt.	18·6	7	20·2
7	Ditto, Flue Dust, grade 2, 7·5 cwt. (Intermediate application)	15·5	4	28·9
8	Ditto, Flue Dust, grade 2, 7·5 cwt. (late application)	17·3	5	23·1
12	Super. 4 cwt., Salt 2 cwt., Dried Sewage Sludge 2 tons	20·2	8	24·4
13	Super. 4 cwt., Salt 2 cwt., Cordite 12 cwt.	21·5	7	23·9
16	No Artificials and no Chalk	18·3	10	21·3
17		18·4	9	19·9
19	No Chalk, Manure as for farm	18·3	7	20·2
20	Chalked, but no Artificials	15·8	all	15·8
21		15·8	all	15·8

[1] There were gaps in these plots. "Best Rows" are rows of full length with all plants growing.

Potatoes. West Barnfield, 1918.

Plot.	Manures per Acre.		Weight per Acre. Tons.
1	Superphosphate 4 cwt., Sulphate of Ammonia 2 cwt.		7·5
2	Super. 4 cwt., Sulphate Amm. 2 cwt., Flue Dust, grade 1, 20·7 cwt.		7·5
3	Ditto ditto	Flue Dust, grade 2, 7·4 cwt.	8·4
4	Ditto ditto	Flue Dust, grade 3, 3·7 cwt.	8·2
5	Ditto ditto	Flue Dust extracted, 6·4 cwt.	8·3
6	Ditto ditto	Sulphate of Potash, 1 cwt.	8·4
7	Ditto ditto	Flue Dust, grade 2, 7·4 cwt. (Intermediate application)	8·4
8	Ditto ditto	Flue Dust, grade 2, 7 cwt. (Late application)	9·0
9	Ditto ditto ...	... ...	8·8
10	Ditto	... ...	8·7
11	Ditto, Nitrate of Amm. 145 lbs.	... ...	8·9
12	Ditto, Sewage Sludge, 2 tons	... ...	8·6
12A	Ditto	... ...	7·8
13	Ditto	... ...	7·3
14	Ditto, Nitrate Amm. 145 lbs.	... ...	8·5
15	No Artificials	... ...	7·2

Flue Dust, grade 1, contains 2·21 p.c. Potash. Flue Dust, grade 3, contains 8·90 p.c. Potash.
,, ,, 2, ,, 5·85 ,, ,, extracted, ,, 7·37 ,,
Sulphate of Potash contains 50·24 p.c. Potash.
The quantities applied were calculated on the basis of 1 cwt. Sulphate of Potash (49 p.c. Potash) per Acre.
NOTE.—All Plots received a dressing of Dung at the rate of 10 tons per acre.

SLUDGE EXPERIMENTS, 1920.

Hay. Great Field Pasture, 1920.

Plot.	Manures per Acre.	Yield per Acre.
		cwt.
1 North	Wet Sludge, 61·7 cwt.	29·3
2	Control	22·0
3 South	Wet Sludge, 61·7 cwt.	22·6
4 North	Sulphate of Ammonia, 1½ cwt.	35·4
5	Control	22·2
6 South	Sulphate of Ammonia, 1½ cwt.	31·0
7 North	Slag, 10 cwt.	25·0
8	Control	21·2
9 South	Slag, 10 cwt.	26·3
10 North	Superphosphate, 6 cwt.	26·3
11	Control	22·9
12 South	Superphosphate, 6 cwt.	22·7
13 North	Nitrate of Ammonia, 114 lbs.	39·6
14	Control	24·9
15 South	Nitrate of Ammonia, 114 lbs.	36·5
16	Nitrolim, 234 lbs.	34·6
17	Control	26·6
18	Nitrolim, 234 lbs.	30·1

Potatoes. Long Hoos Field, 1920.

Plot.	Manures per Acre.	Yield per Acre.
		tons
1	Activated Sewage Sludge, 13·3 tons; Super., 6 cwt. Nitrate of Ammonia, 1 cwt	11·8
4		8·8
3	Farmyard Dung, 15 tons; Super., 6 cwt.; Nitrate of Ammonia, 1 cwt.	10·8
6		9·6
2	Control; Super., 6 cwt.; Nitrate of Ammonia, 1 cwt.	7·8
5		8·3
7		8·9
8		7·9

Barley. Long Hoos Field, 1920.

Plot.	Manures per Acre.	Dressed Grain. Yield per Acre.	Dressed Grain. Weight per Bushel.	Straw per Acre.	Total Produce per Acre.
		Bushels	lbs.	cwt.	lbs.
1	Activated Sewage Sludge, 2·7 tons	36·2	55·5	20·4	4363
4		26·3	56·5	21·1	3897
7		46·3	55·8	28·7	5894
2	Sulphate of Ammonia, 1·45 cwt.	45·1	56·3	25·1	5444
5		38·8	56·3	29·1	5513
3	Control	37·0	55·8	21·8	4557
6		36·5	55·5	23·1	4701
8		39·3	55·5	24·7	5057

METHOD OF SOWING EXPERIMENT.

Wheat. Little Knott Wood, 1918.

Plot.	Treatment.	Dressed Grain.		Straw per Acre.	Total Produce per Acre.
		Yield per Acre.	Weight per Bushel.		
		Bushels	lbs.	cwts.	lbs.
1	Wheat ploughed in after being broadcasted	42·7	61·5	42·5	7543
2	Wheat ploughed in after being drilled	38·6	62·3	40·0	7006
3	Land ploughed, then seed drilled ...	41·9	64·2	43·6	7869

These plots were top dressed on March 12th with 1½ cwt. Super. and 1 cwt. Sulphate Amm. per Acre.

CHALKING EXPERIMENT.

Barley. Stackyard Field, 1919.

Description of Plot.	Dressed Grain.		Straw per Acre.	Total Produce per Acre.
	Yield per Acre.	Weight per Bushel.		
	Bushels	lbs.	cwts.	lbs.
1. Chalked, Autumn, 1912	35·6	55·0	18·7	4150
2. ,, ,, ,, ...	34·8	54·9	18·9	4123
3. } Unchalked	28·9	54·8	15·9	3434
4. }	33·9	55·0	17·0	3850

STRAW EXPERIMENTS.

Treatment.	Yield per Acre in Tons.	
	Arran Chief.	King Edward.
Potatoes. West Barnfield, 1918.		
Raw Straw	7·3	4·9
	7·3	—
Treated Straw	7·3	5·2
	7·4	—
Control	6·8	4·5
	7·0	—
Potatoes. New Zealand Field, 1919.		
Raw Straw	4·7	—
	4·6	—
"Nitrogen" Treated Straw	6·0	—
	6·3	—
"Water" Treated Straw	5·7	—
	5·4	—
Control	6·6	—
	5·9	—

NOTE.—Manures as follows were applied to the West Barnfield potato plots viz., 2½ cwt. Super., 1½ cwt. Sulphate of Amm., and ½ bush. Bone Meal per acre.

PROFESSOR BLACKMAN'S ELECTRO CULTURE EXPERIMENTS, 1919-20.

Clover. Foster's Field.

Description of Plots.	1919 1st Crop. Weight per Acre.	1919 2nd Crop. Weight per Acre.	1919 1st and 2nd Crops. Weight per Acre.	1920. 1st Crop. Weight per Acre.
	cwts.	cwts.	cwts.	cwts.
Electro Plot ...	34·8	17·1	51·9	23·9
Control 1* ...	23·1	14·0	37·1	24·1
Control 2* ...	36·5	—	48·1	23·0
Control 3 ...	—	11·6	---	—

* Control 2 could not be used for second crop of 1919; Control 3 was therefore added. Control 1 is the same for both 1919 crops, but was wired off for the second crop. Controls 1 and 2 both different in 1920 from 1919.
NOTE.—2nd crop 1920 was ploughed in.

WHEAT AND BARLEY.

Description of Plots.		Dressed Grain. Yield per Acre. Bushels.	Dressed Grain. Weight per Bushel. lbs.	Straw. Yield per Acre. cwts.	Total Produce. Yield per Acre. lbs.
Winter Wheat. Great Knott Wood Field, 1919.					
Electro Plots ...	E 1	21·2	60·4	15·6	3210
	E 2	21·9	61·0	18·1	3596
Control Plots ...	C 1	13·9	61·9	11·6	2338
	C 2	16·8	62.3	13.5	2833
Cage Plot	...	8·6	60·5	12·0	2108
Spring Wheat. Great Knott Wood Field, 1919.					
Electro Plots ...	E 3	8·2	56·0	10·7	1845
	E 4	8·2	56·2	11·3	1988
Control Plots ...	C 3	10·6	56·6	10·3	1951
	C 4	8·7	55·0	11·4	1978
	C 5	6·9	55·1	9·8	1676
Wheat (Yeoman). Foster's Field, 1920.					
Electro Plots ...	E 1	18·8	62·2	19·0	3448
	E 2	18·4	62·2	19·7	3536
Control Plots ...	C 1	20·4	62·5	20·5	3697
	C 2	18·2	62·1	17·4	3245
Barley. Foster's Field, 1918.					
Electro Plots ...	E 1	44·7	51·5	22·4	4890
	E 2	47·4	54·0	25·1	5458
	E 3	46·4	53·4	24·4	5284
Control Plots ...	C 1	36·4	52·6	22·1	4456
	C 2	52·7	53·5	29·1	6162
	C 3	36·3	54·0	22·3	4525
Cage Plot	C 4	44·0	54·9	26·3	5453
Barley. Great Knott Wood Field, 1920.					
Electro Plots ...	E 3	31·7	53·1	17·3	3672
	E 4	33·0	53·2	18·5	3889
Control Plots ...	C 3	29·5	53·4	16·0	3410
	C 4	25·2	53·3	12·5	2779

SOIL STERILISING EXPERIMENT.

Wheat after Barley. Long Hoos Field, 1918.

Plot.	Treatment.	Dressed Grain. Yield per Acre. Bushels.	Dressed Grain. Weight per Bushel. lbs.	Straw per Acre. cwts.	Total Produce per Acre. lbs.
1	Cresylic Acid	35·0	63·5	37·9	6745
2	Control	27·7	63·0	30·4	5387
3	Naphthaline	34·5	62·5	38·1	6645

Note.—Dressings on sawdust applied November 2nd, 1917, on Barley Stubble and ploughed in at once. These plots were top dressed as farm, viz. 1 cwt. Sulph. Amm., 1½ cwt. Super. per acre.

MISCELLANEOUS EXPERIMENTS.

Barley. Hoos Field. Leguminous Strips, 1918, 1919, 1920.

Description of Plot.	Manuring per Acre.	1918. Dressed Grain. Bush. per Acre.	1918. Dressed Grain. Weight per Bushel lbs.	1918. Straw per Acre. cwts.	1918. Total Pr'duce per Acre. lbs.	1919. Dressed Grain. Bush. per Acre.	1919. Dressed Grain. Weight per Bushel lbs.	1919. Straw per Acre. cwts.	1919. Total Pr'duce per Acre. lbs.	1920. Dressed Grain. Bush. per Acre.	1920. Dressed Grain. Weight per Bushel lbs.	1920. Straw per Acre. cwts.	1920. Total Pr'duce per Acre. lbs.
After Lucerne ...	Sulphate Amm. 1½ cwt. ...	20·1	55·3	10·7	2340	15·8	53·1	7·9	1790	27·3	52·8	20·5	3837
	S. Amm. 1½ cwt. Super. 3 cwt.	27·4	54·8	11·1	2777	18·4	54·1	8·0	1939	46·3	53·2	20·0	4799
After Red Clover	Sulphate Amm. 1½ cwt. ...	19·4	54·8	9·6	2170	12·5	53·3	6·9	1493	16·3	53·1	15·9	2719
	S.Amm. 1½ cwt.; Super. 3 cwt.	22·9	54·4	9·1	2282	16·1	54·6	6·6	1651	33·5	52·3	16·1	3630
After Alsike ...	Sulphate Amm. 1½ cwt. ...	17·5	54·2	8·5	1930	10·6	53·6	6·7	1375	15·5	53·4	15·8	2657
	S.Amm. 1½ cwt.; Super. 3 cwt.	21·4	53·8	8·7	2185	15·4	54·0	6·8	1621	38·0	52·1	18·6	4116

Leguminous crops ploughed in November, 1911. For crop yields, see previous Reports. In 1915 the land was fallow; in 1916 and 1917, barley with clover: no separate weighings were kept, however.

Mangolds. Long Hoos Field, 1919.

Plot.	Description of Plot.	Manuring per Acre.	Weight of Roots per Acre. Tons.
A	Bouted	20 tons of Dung, 3 cwt. Super., 1½ cwt. Sulphate Ammonia, applied on May 23 and a further 2 cwt. Sulphate Ammonia, applied July 28 ...	11·0
B	Flat		6·5
C	Bouted		9·0

Hoos Field. Barley sown with Clover, **1920**.

(Formerly Barley after Alsike, p. 84). Clover cut with Barley and weighed.

Plot.	Manures per Acre.	Clover. Yield per Acre.	Barley. Yield per Acre.	Total Produce per Acre.
		cwts.	cwts.	cwts.
1	8 cwt. Slag, 10 cwt. Lime	6·7	31·7	38·4
2	5 cwt. Super., 10 cwt. Lime, 14 tons Dung	15·2	31·2	46·4
3	10 cwt. Lime	4·9	27·7	32·6
4	5 cwt. Super., 1·5 cwt. Sulph. Potash, 10 cwt. Lime	9·8	28·1	37·9
5	5 cwt. Super., 10 cwt. Lime	7·1	28·6	35·7
6	10 cwt. Lime	4·5	30·4	34·8
7	10 cwt. Lime, 14 tons Farmyard Dung ...	8·5	41·5	50·0
8	8 cwt. Slag	5·4	21·9	27·3
9	5 cwt. Super., 14 tons Farmyard Dung ...	14·7	21·9	36·6
10	*Control*	*3·6*	*21·9*	*25·5*
11	5 cwt. Super., 1·5 cwt. Sulph. Potash ...	12·5	24·1	36·6
12	5 cwt. Super.	9·4	24·1	33·5
13	*Control*	*6·3*	*22·3*	*28·6*
14	14 tons Farmyard Dung	13.0	27·2	40·2
15	10 cwt. Lime, 14 tons Horse Manure ...	11·2	14·7	25·9
16	*Control*	*4·9*	*14·3*	*19·2*
17	14 tons Horse Manure	11·2	13·8	25·0
18	5 cwt. Super....	4·0	22.8	26·8
19	10 cwt. Lime, 14 tons Cattle Manure ...	8·5	29·5	38·0
20	*Control*	*4·5*	*26·3*	*30·8*
21	14 tons Cattle Manure	7·6	30·4	38·0

Manures sown March 13th, 1920. Horse, Cattle and Farmyard (Mixed) Manure put on Feb. 20th and 21st, 1920. Barley Seed sown March 19th, 1920. Clover Seed drilled between Barley rows, May 1st, 1920.

Wheat after Clover in **1917**. Little Hoos Field, **1918**.

Plot.	Manures per Acre.	Dressed Grain. Yield per Acre.	Straw per Acre.	Total Produce per Acre.
		lbs.	cwts.	lbs.
1	Control	2195	34·9	6323
6		2325	38·7	6937
3	Superphosphate 2 cwt.	2493	39·5	7190
8		2197	39·3	6905
2	Super. 2 cwt., Sulphate Amm. 1 cwt. ...	2630	45·8	8058
5		2585	42·1	7655
4	Super. 2 cwt., Nitrate Amm. 72 lbs. ...	2823	44·2	8000
7		2400	44·0	7710

Lawes Agricultural Trust

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