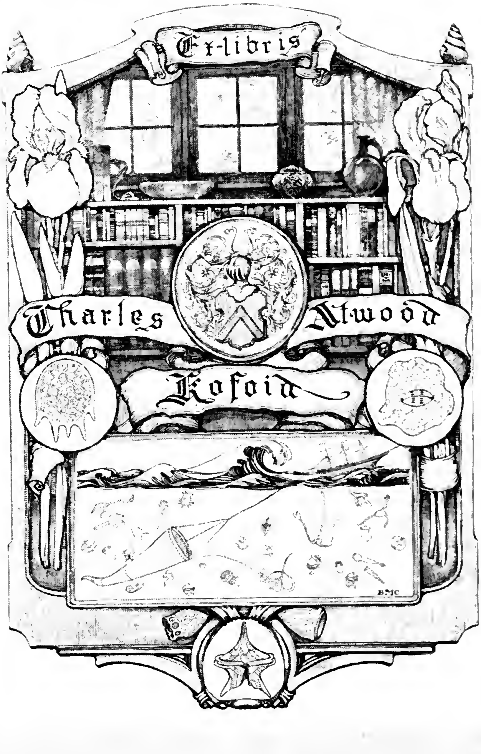
THE ROTHAMSTED EXPERIMENTS.

FREAM.


Ex-libris
Charles Atwood
Kofoid
BMC

THE

ROTHAMSTED EXPERIMENTS

ON THE

GROWTH OF WHEAT, BARLEY,

AND THE

MIXED HERBAGE OF GRASS LAND.

BY

WILLIAM FREAM, B.Sc. Lond., F.L.S., F.G.S., F.S.S.,

ASSOCIATE OF THE SURVEYORS' INSTITUTION; CONSULTING BOTANIST TO THE BRITISH DAIRY FARMERS' ASSOCIATION AND THE ROYAL COUNTIES AGRICULTURAL SOCIETY; PROFESSOR OF NATURAL HISTORY IN THE COLLEGE OF AGRICULTURE, DOWNTON, SALISBURY, AND FORMERLY PROFESSOR OF NATURAL HISTORY IN THE ROYAL AGRICULTURAL COLLEGE, CIRENCESTER.

LONDON:

HORACE COX, "THE FIELD" OFFICE, 346, STRAND, W.C.

1888.

LONDON:
PRINTED BY HORACE COX, 10, WELLINGTON STREET, STRAND, W.C.

TO

SIR JOHN BENNET LAWES, BART., LL.D., F.R.S.,

AND

PROF. JOSEPH HENRY GILBERT, M.A., LL.D., F.R.S.,

WHOSE LONG-CONTINUED AND SUCCESSFUL
INVESTIGATIONS IN EVERY DOMAIN OF
AGRICULTURAL INQUIRY HAVE MADE
THE NAME OF THE ROTHAMSTED
EXPERIMENTAL STATION
FAMOUS THROUGHOUT
THE WORLD,
THIS VOLUME, RECORDING THE METHODS AND
RESULTS OF SOME OF THEIR RESEARCHES,
IS BY PERMISSION RESPECTFULLY

Dedicated.

PREFACE.

Having had occasion to study somewhat closely the work of the Rothamsted investigators, it occurred to me that their valuable memoirs, dealing as they so largely do with actually ascertained results, might be advantageously condensed into the form of a text-book. Hence arose the present volume which, though it is concerned with a portion only of the many questions that have been brought within the range of experimental inquiry at Rothamsted, yet deals with subjects of first class importance, equally in their scientific bearing as in their economic aspect. To the student the discussion of concrete results should prove at least as useful as the consideration of abstract assertions, whilst it is possible that it may be even more suggestive.

In the endeavour to make each subject as far as possible complete in itself, a certain amount of repetition has been unavoidable. Many questions, again, which are but lightly touched upon in these pages, are more fully dealt with in other of the Rothamsted memoirs than those which the writer has laid under contribution. Even as this work is passing through the press a fresh memoir issuing from Rothamsted throws further light upon the classical inquiry as to the sources of the nitrogen of vegetation.

In several instances the information here given is brought very nearly down to date. This has been rendered possible only through the characteristically kind and ready manner in which Sir John Lawes and Dr. Gilbert have responded to my requests, and for which my grateful acknowledgments are tendered.

At the present time, when there has been preferred a somewhat vague demand that the Government should undertake the support of agricultural experiment stations, it seems a fitting moment in which to make more widely known the nature and results of the splendid work which private enterprise has with such conspicuous success maintained at Rothamsted. Whatever merits this book may possess are due to the illustrious investigators with whose name the volume is associated. Its faults, whatever they be, are mine alone.

W. FREAM.

College of Agriculture,
Downton, Salisbury,
January, 1888.

CONTENTS.

BARLEY.

GRASS.

E R R A T A.

Page 75, last line.—*For* " estimates " *read* " estimate.'
Last line but one.—*For* " 1787 " *read* " 1887.'

THE

ROTHAMSTED EXPERIMENTS.

I.—INTRODUCTORY.

The history of the oldest agricultural experimental station in the world is soon told. Sir (then Mr.) John Bennet Lawes, Bart., entered into possession of his hereditary property at Rothamsted, Hertfordshire, in 1834, and soon afterwards commenced that unique series of experimental investigations which are still in progress, and for which, through the munificence of their originator, provision has been made for the continuation in perpetuity. In June, 1843, Dr. J. H. Gilbert became associated with Mr. Lawes, and undertook the direction of the chemical laboratory; at this time, also, the more systematic field experiments were commenced. The general scope and plan of these field experiments is stated in the following words: To grow some of the more important crops of rotation, each separately, year after year, for many years in succession on the same land, without manure, with farmyard manure, and with a great variety of chemical manures; the same description of manure being, as a rule, applied year after year on the same plot. Experiments on an actual course of rotation, without manure, and with different manures, have also been made. In this way field experiments have been conducted with wheat, barley, oats, beans, clover, various leguminous plants, turnips, sugar beet, mangel wurzel, potatoes, and permanent grass. Comparative experiments with different manures have also been made, on other descriptions of soil, at Holkham and Rodmersham. Samples of the soils, of the crops, and of different portions of the crops are taken to the laboratory and subjected to exhaustive chemical analysis, and it is on the results of such examinations that the conclusions are based. Other inquiries have embraced the investigation of soils, especially with reference to the percentages of nitrogen they contain at different depths, the chemical constituents in rain and in drainage waters, the amount of water transpired by plants, and experiments on the assimilation of free nitrogen by vegetation.

Equally important experiments with farm animals were commenced in 1847. Among the points which have been investigated are: (1) The amount of food, and of its several constituents, consumed in relation to a given live-weight of animal within a given time. (2) The amount of food, and of its several constituents, consumed to produce a given amount of increase in live-weight. (3) The proportion, and relative development, of the different organs or parts of different animals. (4) The proximate and ultimate composition of the animals in different conditions as to age and fatness, and the probable composition of their increase in live-weight during the fattening process. (5) The composition of the solid and liquid excreta (the manure) in relation to that of the food consumed. (6) The loss or expenditure of constituents by respiration and the cutaneous exhalations—that is, in the mere sustenance of the living meat-and-manure-making machine. Oxen, sheep, and pigs have been the subjects of the experiments, and the results obtained have further been of use in furnishing data for the consideration of the following questions: (1) The characteristic demands of the animal body (for nitrogenous or non-nitrogenous constituents of food) in the exercise of muscular power. (2) The sources in the food of the fat produced in the animal body. (3) The comparative characters of animal and vegetable food in human dietaries.

Supplementary investigations have included a somewhat exhaustive inquiry into the application of town sewage to different crops, and especially to grass; the chemistry of the malting process, the loss of food constituents during its progress, and the comparative feeding value of barley and malt; the changes and losses which food crops undergo in the process of conversion into silage; and the feeding value of different kinds of silage when supplied to fattening oxen and to milking cows.

The first original paper that emanated from Rothamsted appeared in the year 1847, and from then to the middle of 1887—that is, during a period of forty years—there were published as many as one hundred and four separate papers or memoirs. A rough classification of these papers leads to some such arrangement of subjects as the following: (1) Experiments on the continuous growth of wheat and of barley on the same land. (2) Agricultural, botanical, and chemical results of experiments on the mixed herbage of permanent meadow conducted for more than twenty years in succession on the same land. (3) The amount and composition of rain and drainage water. (4) The application, distribution, and influence of manures, and the valuation of unexhausted manures. (5) The fertility and exhaustion of soils. (6) The combined nitrogen in soils and subsoils. (7) The sources of the nitrogen of vegetation. (8) Nitrification. (9) Clover sickness and the growth of clover by different manures. (10) The evaporation of water from plants. (11) The botany and chemistry of fairy rings. (12) The home produce, imports, and consumption of wheat, and the composition of wheat grain, mill products, and bread. (13) Agricultural chemistry, dealing with Liebig's theories, with turnip culture, and with the feeding of oxen, sheep, and pigs. (14) The utilisation of town sewage. (15) The relation of temperature to plant-growth.

It is when the inquirer, who wishes to obtain an adequate idea and a comprehensive view of the Rothamsted experiments, seeks to study the published results, that the initial difficulty is met with. For where shall they be sought? The answer is, in the journals of a dozen different societies, in magazines, in parliamentary papers, and some of them in the form of separate memoirs. About three dozen papers have been communicated to the Journal of the Royal Agricultural Society. Numerous other papers have appeared in the Journal of the Royal Horticultural Society, the Journal of the Chemical Society, the Journal of the Linnean Society, the Journal of the Statistical Society, the Journal of the Society of Arts, the Report of the British Association, the Proceedings of the Institution of Civil Engineers. and the Proceedings of the Royal Society. Others, again, must be sought in the Archives des Sciences physiques et naturelles, in the Philosophical Magazine, in the Journal of Anatomy and Physiology, and in the Edinburgh Veterinary Review. About ten papers were published as independent pamphlets, whilst between 700 and 800 of the large quarto pages of the Philosophical Transactions, issued by the Royal Society, are occupied with reports of the classical researches on the sources of the nitrogen of vegetation, the composition of some of the animals fed and slaughtered as human food, and the mixed herbage of permanent meadow.

The difficulty experienced by the Rothamsted investigators in keeping their current publications at all abreast of their researches effectually precludes the hope of our getting from Rothamsted itself any connected history of the work of the last half century Such a history would be gladly welcomed by progressive agriculturists in all parts of the world, for it is now impossible to obtain some of the original memoirs. Mr. Warington, of the Rothamsted Laboratory, has tersely observed that "the best English work on agricultural chemistry exists as yet only in detached papers." Nearly all these "detached papers" have emanated from Rothamsted, and the object of the following pages is to present to the reader in a succinct and collected form a description of the Rothamsted experiments on wheat, barley, and grass.

The first part of the book is concerned with experiments upon the growth of wheat, and concludes with a discussion of some important economical questions. The second part is occupied with experiments upon the growth of barley. The third and last part deals with experiments upon the mixed herbage of permanent meadow. In each part there occur many incidental references to the natural resources of the soil, and to the nature of the loss occasioned by the drainage waters, whilst much light is thrown upon the celebrated problem as to the sources of the nitrogen of vegetation. The numerical tables, most of which are quoted *in extenso* from the original memoirs, are invaluable, and are specially commended to the attention of students.

These experiments are unique, and their fame has spread wherever modern agriculture is practised. To the cultivator of the soil they afford the best examples of the method of conducting such investigations, whilst to the agricultural student on the one hand, and to the chemist and physiologist, the statistician and economist, on the other, a study of them is indispensable.

II.—EARLY EXPERIMENTS ON WHEAT.

1. THE HOLKHAM EXPERIMENTS.

Of the experiments on the growth of wheat, by far the most noteworthy are those concerned with the growth of this cereal for forty years in succession on the same land. But there are two earlier reports which possess a special value, inasmuch as they very well serve to indicate the type of experiment which might be advantageously repeated either by agricultural societies or by private enterprise. The first of these, published in the R.A.S. Journal, 1855, bears the title "Report to the Right Hon. the Earl of Leicester, on the experiments conducted by Mr. Keary, on the growth of wheat upon the same land for four successive years, at Holkham Park Farm, Norfolk."

With regard to the terms "light" and "heavy," as applied to soils, it is pointed out in this report that, as applied to a *surface soil*, they afford a very imperfect indication of the probable native resources, and consequently of the capabilities of growth without deterioration, of the respective soils. Here is suggested a vein of inquiry which has since been profitably worked at Rothamsted. The soil on which the experiments at Holkham were made is described as a light, thin, and rather shallow brown sand loam, resting upon an excellent marl containing a large quantity of calcareous matter. In such a surface soil there would be combined the easily working qualities and the power of rapidly yielding up manurial matter of the so-called "light" soils, whilst in its subsoil there would be much of the native resource of constituents, and probably the power of absorption or retention of manurial matter also, of the so-called heavy soils. But it was of the greatest interest to ascertain by actual experiment how far those chemical substances, which are employed with success for the increased growth of wheat upon heavy soils, could be used with advantage upon those of different descriptions.

Previous to the introduction of the four-course system by the late Earl of Leicester, the soil upon which the experiments were made had been considered too light to grow wheat. The land had for some years previous to the experiments been farmed under that system; it was clayed about twelve years before the experiments were begun, and the crop immediately preceding them was white turnips, manured with farmyard dung and guano, both tops and roots being drawn off the land. The experimental plots measured half an acre each; the manures were as follows, and were all sown in the autumn, except plot 4, which was sown in spring:

Plot 1. Always unmanured.
Plot 2. Mineral manures alone.
Plot 3. Ammonia-salts alone, sown in the autumn.
Plot 4. Ammonia-salts alone, sown in the spring.
Plot 5. Both the mineral manure and ammonia-salts.
Plot 6. Rape cake.
Plot 7. Farmyard manure.

1. The unmanured plot, when once exhausted of the accumulations derived from the more recent previous manuring, would, of course, show the productive capability of the soil in a comparatively normal state, in conjunction with that of the annual climatic yield of the atmospheric elements of growth; and the results would provide a standard with which to compare the produce of the different manures.

2. The mineral manure furnished a liberal supply of the alkalies (potash and soda), alkaline earths (lime and magnesia), and phosphoric acid; and its produce, compared with that of the other plots, shows whether the result of the

cropping is to reduce the available supplies of such mineral constituents in the soil below that which is requisite to obtain the full benefit of the annual atmospheric supply of carbon and nitrogen, or whether it is the supply in the soil of the carbon or the nitrogen which is most exhausted.

3. The use of ammonia-salts alone, which provide nitrogen for the growth of the crop, shows whether or not the latent mineral wealth of the soil is more than sufficient for the annual atmospheric supply of available nitrogen.

4. And the object of sowing one plot with ammonia-salts in the autumn and another in the spring was to determine whether it was practically advantageous to sow such soluble manures in the autumn on so light a soil.

5. The mixture of mineral manures and ammonia-salts shows, when the results are compared with those of each of these manures used separately—first, whether the annually available native mineral supply of the soil, taken together with that in the manure, was not capable of producing a much greater amount of growth than was the annual atmospheric supply of nitrogen; and, secondly, whether the amount of nitrogen supplied to the soil, when such a quantity of ammonia-salts was used alone, was not in excess in proportion to the annually available supply of minerals from the soil itself.

6. Rape-cake contains a large proportion of carbonaceous and nitrogenous organic substances, and some mineral matter; and the nitrogen supplied in the quantity of it used was nearly identically the same as, or, perhaps, rather greater in amount than, that in the ammonia-salts of the other experiments.

7. The farmyard manure was the product of yards in which bullocks were fed on turnips with a moderate quantity of oil cake. In this manure there would be added to the soil every year a larger supply of every constituent than was contained in the increased wheat crop grown.

The results are summarised in a series of tables, in which are stated the dressings of manure per acre on each plot, and the yields of dressed corn, offal corn, and straw in each of the four seasons, 1851-2-3-4.

In every case a larger produce, by 14 to 20 bushels, or even more, was obtained by the same manure in the first year than in the average of the following years. This result speaks well for the previous "condition" of the land, and it is also very instructive as showing how useless, for the purposes of any general conclusions, are experiments with manures conducted over a single season only. It is in fact not until some of the elements of fertility, the due proportion of which to the others is indicated in the term "condition," have been removed from the soil by the crop, that any safe deductions can be formed from the results of experiments with manures.

Plot 1, unmanured, gave 39½ bushels per acre of dressed corn the first year, 15½ the second, 21½ the third, and 16¾ the fourth, the average of the four years being 23¼ bushels, and that of the last three years nearly 18 bushels, which latter amount is nearly 22 bushels less than was obtained on the same plot in the first year.

Plot 2, manured with salts of potash, soda, and magnesia, and superphosphate of lime, gave in the four years respectively 34½, 19, 19¾, and 18½ bushels of dressed corn per acre, the average of the last three years being about 15 bushels less than the yield of the first year. A comparison of the results on plots 1 and 2 shows that there was actually rather more corn obtained without manure than with the minerals, the tendency of the latter being to increase the growth of straw, of which, taking the last three years together, there was about half a ton more obtained by means of the minerals.

Plot 3 received in the autumn, and plot 4 in the spring, 200lb. sulphate of ammonia, and 200lb. muriate of ammonia per acre. Taking the four years together, there is a difference of less than 2 bushels between the produce of the two plots, it being, however, rather in favour of the autumn-sown manure. In straw there is a difference of only 8lb. per acre in favour of the spring-sown manure. Upon the whole, then, the results are in favour of sowing these soluble manures in the autumn, even in so light a soil. On the autumn-sown plot there was a fall in the produce of 18 bushels, and on the spring-sown plot of 14½ bushels per acre, from the first year to the average of the last three years.

Plot 5 received the same manure as plot 2, and as plot 3 or 4. The result was to produce over the four years from 53 to 54 bushels of corn more than was yielded by the minerals alone, besides a larger quantity of straw. This, therefore, was an annual average of 13 to 14 bushels of corn, and an equivalent of straw, due to the use of the ammonia salts. And since there was in the four years about twenty bushels more increase by the mixture of both minerals and ammonia-salts than by the latter alone, it is obvious that the minerals of this last 20 bushels of the total 53 of increase were derived from the mineral manures employed.

On plot 7, 14 tons per acre of farmyard manure were annually applied, and gave an average annual increase of about 10½ bushels of corn and 1300lb. of straw—less by nearly 3 bushels of corn and about 150lb. of straw than the produce obtained by the rape-cake (plot 6). As the other plots demonstrated, in their results, that neither minerals alone, nor carbonaceous organic matter (in the rape cake), had any influence in the increase of the crop, but that wherever there was a supply of nitrogen in the manure there was always a very considerable increase, it is concluded that it was the amount of nitrogen liberated from the dung, in a form assimilable by the plants, which determined the limit to the increase of produce obtained by its use. Though the amount of nitrogen contained in the increased produce of wheat was never equal to that supplied in the manure, it is to be remembered that, besides any liability to loss by drainage, to which all manurial ingredients might be subject, the nitrogen, in several of its forms of combination, is also volatile, and might be exhaled into the atmosphere and so lost. This is not the case with the mineral constituents of manure.

Upon the whole a careful study of these experiments proves:

1. That the soil, even with the most unusual and very exhausting process of carrying off the land the total grain and straw of several successive corn crops, after a root crop which had also been drawn from the land, still contained a larger annual available supply of minerals than the annual natural supplies of other constituents, nitrogen or carbon, were adequate to turn to account.

2. That the excess of the annual supply of minerals in the soil over that required to appropriate the natural resources of nitrogen is proved, by the effects of ammonia-salts alone, to have been equal to the further growth, during four years, of about 32 bushels of wheat, or an average of about 8 bushels per annum.

3. That beyond the increased annual produce which the supply of minerals in the soil was adequate to provide when nitrogen was not wanting, the average capabilities of the climate were competent for the maturing of a still greater produce, if additional minerals as well as the ammonia-salts were provided; and, in that case, from once and a half to twice as much corn was grown as the natural supplies of nitrogen, even with a most liberal supply of minerals, were sufficient to produce.

4. That carbonaceous organic matters (such as are contained in rape cake and farmyard manure) are of themselves of little or no effect in increasing the growth of wheat.

The concluding words of this paper, written more than thirty years ago, are still of interest: There cannot be a doubt of the legitimacy of the inference from these and other experiments that, provided the land receive in a course of years a due share of the home manures derived from feeding of horses and other stock on the farm, the mineral supplies of the soil will be amply sufficient to sustain an increased and even repeated growth of corn, by means of nitrogenous artificial manures, considerably beyond that which is recognised by the leases or the current practices of the day ; and a further assurance that the necessary minerals are not likely to become deficient, under the judicious adoption of such an increased growth of corn, is to be found in the fact that there are few really large sources of nitrogenous manures which do not, at the same time, bring upon the land a considerable amount of some of the more important minerals also.

2.—THE RODMERSHAM EXPERIMENTS.

One other series of experiments, besides those at Holkham, was carried out away from Rothamsted, and is of equal interest with the Holkham series in suggesting the nature and character of the field investigations which might be conveniently prosecuted in various localities, either by private enterprise or under the auspices of an agricultural society. The "Report of experiments made at Rodmersham, Kent, on the growth of wheat by different descriptions of manure for several years in succession on the same land," appeared in the R.A.S. Journal, 1862. The scheme of these experiments was similar in essential details to that of the Holkham Park Farm experiments, and both were modelled upon those which then were, and still are, in progress at Rothamsted on the continuous growth of wheat upon the same land. The Rodmersham experiments arose in this wise: Sir John M. Tylden, the president of an agricultural club in the neighbourhood of Sittingbourne, Kent, induced the members to visit Rothamsted; and the consequence was that they undertook to conduct, at their own expense, a series of experiments on the growth of wheat, the results of which might be compared with those of the experiments at Holkham and Rothamsted.

Accordingly, a field of 3½ acres at Rodmersham, about three and a half miles from Sittingbourne, was divided into seven plots of half an acre each, and the experiments were placed in charge of Mr. George Eley, of Tong, the secretary of the club. The soil of the experimental plots is described as a mixed clay, upon a chalk subsoil lying from 4ft. to 6ft. below the surface. The previous cropping had been as follows: In 1853, turnips, dressed with 2cwt. guano and 3cwt. superphosphate of lime per acre, and the whole of the crop fed on the land; in 1854, barley, and a good dressing of London dung for beans in 1855, this being the usual preparation for wheat in that locality. The land was, therefore, in a well-cultivated and fertile state, and, as the results showed, in higher condition than was desirable when the object was to determine the character of the exhaustion, and therefore the character of the manures required for the crop in that particular soil, under the ordinary system of cropping and management adopted. The action of the different manures was, nevertheless, sufficiently characteristic after the first crop of wheat had been taken.

The manures were obtained from the bulks used in the Rothamsted experiments. The arrangement and quantities per acre were as follows:

Plot 1. Unmanured.

Plot 2. Mixed mineral manure, viz., 300lb. sulphate of potash, 200lb. sulphate of soda, 100lb. sulphate of magnesia, 350lb. superphosphate of lime (consisting of 200lb. bone ash and 150lb. sulphuric acid of sp. gr. 1·7).

Plot 3. Ammonia-salts, comprising 200lb. sulphate of ammonia and 200lb. muriate (chloride) of ammonia.

Plot 4. Ammonia-salts (as Plot 3) and mixed mineral manure (as Plot 2).

Plot 5. 540lb. Peruvian guano.

Plot 6. 2000lb. rape cake.

Plot 7. 14 tons farmyard manure.

The dressings were applied annually for the first three years, and the arrangement was the same for the fourth year, save that on Plots 2 and 4 the quantities of sulphate of potash were reduced from 300lb. to 200lb., and of sulphate of soda from 200lb. to 100lb. per acre. In the fifth and sixth seasons the crop was grown without any fresh application of manure.

The object of experiment 1 was to ascertain the state of productiveness of the land without any manure, and so to provide a standard by which to compare the effects of the different manures. Experiments 2, 3, 4, 6, and 7 were to determine whether a specially mineral, nitrogenous, or carbonaceous manure, or some combination of these, is the most effective, and experiment 5 would indicate whether increase of crop can be profitably obtained by a cheap "artificial" manure containing a large proportion both of nitrogen and phosphates.

The results of the six years' experiments (1856-61) as collected in a series of tables may now be discussed. It is noteworthy that after the land had been well dunged, and had grown a crop of beans, the greatest increase, especially of grain, obtained in the first year was where the manure was the most nitrogenous. Thus, the ammonia-salts alone, the guano, and the rape cake each gave 4 to 5 bushels increase of dressed corn; whilst the mineral manure, and the mineral manure and ammonia-salts together, gave only about one bushel. The ammonia-salts alone also gave rather more increase of straw than any of the other manures, more even than the mixed mineral manure and ammonia-salts together. The produce of the unmanured plot in the second and succeeding years showed, however, that the condition of the land had then become reduced; and it is therefore from the average results of each of the different manures taken over a series of years that it is most convenient to judge of the character of the exhaustion induced by the growth of the wheat crop in that particular soil.

Generally, the results obtained during the four years that the manures were applied showed that mineral manures increased the wheat crop but little, ammonia-salts much more, mineral manures and ammonia-salts used together more than either, or both, used separately; that Peruvian guano, containing both mineral and nitrogenous constituents, gave a considerable amount of increase, but that carbonaceous manures had no perceptible effect. They further showed that the condition of the land was higher than was desirable for the purposes of the experiments, the result of which was, not only that the seasons set a limit to the amount of crop, and therefore to that of the increase produced, below that which the manures might otherwise have yielded, but that the increase consisted of a very undue proportion of straw.

Passing now to the fifth and sixth years, in which all applications of manures were withheld, the results corroborated the conclusion already arrived at, that the condition of the land was too high for the full action of the manures in the years of their application. They likewise showed that their influence was not even then exhausted, and this is further proved by the fact that calculation shows there was a less proportion of the nitrogen supplied in the manures in the four years recovered in the increase of the six years, and in some cases much less, than is sometimes recovered in the crop immediately succeeding the application of a nitrogenous manure. Under favourable circumstances, from 40 to 50 per cent. of the nitrogen supplied in an artificial manure for wheat may be recovered in the increase of a first crop. But it is estimated that, in the cases of the rape cake and of the ammonia-salts alone, there was only about one-fourth, and in those of the mineral manure and ammonia-salts, and of the guano, under 40 per cent. of the nitrogen supplied in the manure of the four years recovered in the increase of the six years.

A comparison of the value of the increase of crop with the cost of the manures applied shows that the mixed mineral manures of Plot 2 were far too expensive in proportion to the amount of increase they yielded for it to be at all worth while to reckon the cost against the increase in their case. Ammonia-salts are generally neither so cheap a source of nitrogen, nor are they, when used alone, so good a manure for corn crops, as Peruvian guano, which contains a large proportion of phosphates as well as nitrogen. Rape cake, though a recognised manure in the market for wheat, acts somewhat more slowly for the amount of nitrogen it contains than does guano. It will be well, for the sake of comparison, to show the cost of the manures at the period of the experiments, and the value of the increase due to the three manures — rape cake, ammonia-salts, and Peruvian guano:

Manures applied per acre in four years.			Increase obtained per acre in six years.				Cost of manure.	Value of increase.	Difference.
			Corn.		Straw.				
Description.	Quantities.	Price per ton in 1862.	Bushels.	Price per bushel, 1862.	Cwts.	Price per cwt. 1862.			
	lb.	£ s.		s. d.		s. d.	£ s. d.	£ s. d.	£ s. d.
Rape cake	8000	5 10	46¾	7 0	75¼	1 3	19 12 10	21 1 4	1 8 6
Sulphate of ammonia	800	15 0	36	7 0	69¾	1 3	12 10 0	16 19 2	4 9 2
Muriate of ammonia	800	20 0							
Peruvian guano	2160	12 10	45½	7 0	91¾	1 3	12 1 1	21 13 2	9 12 1

Reckoning the value of the increase against the cost of the manures, there is a considerable margin in favour both of the ammonia-salts and the guano, particularly the latter. The evidence further indicates that these active nitrogenous manures are by no means fully exhausted in the first year of their application. The quantity of guano employed—nearly 5cwt. to the acre—was, however, more than it is desirable to apply in ordinary practice. And it should not be inferred that the practice of growing a series of corn crops by means of artificial manures is to be recommended. Nevertheless, the practical conclusion undoubtedly is that highly nitrogenous manures much increase the produce of grain crops under the circumstances in which these are generally grown n our rotations.

III.—EXPERIMENTS ON THE CONTINUOUS GROWTH OF WHEAT UPON THE SAME LAND FOR FORTY YEARS.

Wheat has now been grown for more than forty years in succession on the same land at Rothamsted, and since the eighth year of the experiments each plot has, year after year, received uniform treatment as regards manuring, the variations in this latter respect comprising (1) without manure, (2) with farmyard manure, (3) with a great variety of chemical manures. As an example of an experiment in which the same kind of crop is grown on the same land, subject to uniform manurial treatment, year after year, this elaborate investigation is unique, both in its long continuation and in the maintenance of uniformity of conditions. To the R. A. S. Journal, Messrs. Lawes and Gilbert contributed, in 1864, the "Report of experiments on the growth of wheat for twenty years in succession on the same land," and, twenty years later, there appeared the "Report of experiments on the growth of wheat for the second period of twenty years in succession on the same land." These papers occupy altogether about 240 pages, some eighty of which are devoted to figures in the form of appendix tables. It will be convenient to discuss the report in its entirety, as that of forty years' continuous experiment.

In commencing their first report, the authors remark that the records of a field of 14 acres, in which wheat has been grown without manure, and by different descriptions of manure, year after year, for twenty successive seasons, without either fallow or a fallow crop, and in which the lowest produce was in the first year 15, and in the last $17\frac{1}{4}$

bushels, and the highest in the first year 24¼, and in the last 56½ bushels, cannot fail to be of much interest at once to the farmer, to the economist, and to the man of science. Much more, then, is this true of records which now extend over a period twice as long. The experiments have been made on what may be called fair average wheat land. The rent of similar land in the locality ranged from 25*s.* to 30*s.* per acre, tithe free, and its wheat crop under the usual management of the district, did not average more than 25 to 27 bushels per acre every fifth year, so that the land could lay no claim to extraordinary fertility, or to be ranked on a higher level than a large proportion of the soils on which wheat is grown with a moderate degree of success, under a system of rotation and home manuring. The soil is a somewhat heavy loam, with a subsoil of raw yellowish red clay, but resting in its turn upon chalk, which provides good natural drainage.

PLAN OF THE EXPERIMENTS.

The reports include accounts of the amount and character of the produce obtained in every one of the forty seasons from 1843 to 1883, a general description of the weather in each season being accompanied by a table showing the manures applied and a summary of the results obtained. The appendix tables show the effects of one manure compared with those of another in each season separately, and the great difference of effect of the same manure in one season compared with another, and its increasing or diminishing effect when used year after year on the same plot. But as it is essential to know not only the quantity, but likewise the chemical composition of the produce, determinations have each year been made of the proportions of dry substance and of mineral matter in both the grain and the straw of each plot. The proportion and quantity per acre of the nitrogen, and the composition of the ash, in both grain and straw, have in many selected cases been determined. The percentage of nitrogen in the soil of some of the plots, at different stages of the progress of the experiments, has also been estimated.

One useful result of a study of the Rothamsted experiments is that intending investigators may learn, not only what methods are best to follow, but those which it is desirable to avoid. As already mentioned, these wheat-growing experiments were not during the first eight years carried out with uniformity of manuring on each plot. Referring to this point, the experimenters observe, in the introduction to their second report, that an attempt to investigate the growth of wheat, under circumstances so totally different from any which had ever previously arisen, could hardly be carried out without the commission of some errors which experience would have enabled them to avoid. They have now ascertained that, if it is desired to advance beyond the question of the best manure to grow one crop of wheat, continuity of the same manuring is of supreme importance. With the exception of the plot receiving farmyard dung, and the unmanured plot—neither of which has been altered from the commencement—there is no plot in the field in which some change did not take place in the manure applied during the early years of the experiments. But in the autumn of 1851, eight years after the experiments were commenced, the manuring of the field was arranged upon a fixed plan which, with very slight changes in one or two instances, has been followed ever since.

As, therefore, the manurial treatment of each plot has, since 1852, not been varied, it will be convenient to state here, once for all, the description and quantities, estimated per acre per annum, of the several manures:

Plot 2.—14 tons farmyard manure (also for the eight preceding years).

Plot 3.—Unmanured (also for the eight preceding years).

Plot 20.—Unmanured (also for five preceding years).

Plot 4.—Unmanured (sulphate of ammonia and bone ash acted upon by hydrochloric acid, for seven preceding years).

Plot 0.—Superphosphate of lime alone, composed of 600lb. bone ash and 450lb. sulphuric acid, sp. gr. 1·7 (also for three preceding years).

Plot 1.—Mixed alkalies, composed of 600lb. sulphate of potash, 400lb. sulphate of soda, and 200lb. sulphate of magnesia (also for three preceding years); reduced to 400lb., 200lb., and 200lb., respectively, in the sixteenth and succeeding seasons.

Plots 5 (*a* and *b*).—Mixed mineral manure, composed of 300lb. sulphate of potash, 200lb. sulphate of soda, 100lb. sulphate of magnesia, and 350lb superphosphate of lime (consisting of 200lb. bone ash and 150lb. sulphuric acid, sp. gr. 1·7). In the sixteenth and succeeding seasons, the sulphate of potash was reduced to 200lb., and the sulphate of soda to 100lb.

Plot 21.—Mixed mineral manure, as plots 5, and 100lb. muriate of ammonia.

Plot 22.—Mixed mineral manure, as plots 5, and 100lb. sulphate of ammonia.

Plots 6 (*a* and *b*).—Mixed mineral manure, as plots 5, and 100lb. each sulphate and muriate of ammonia.

Plots 7 (*a* and *b*).—Mixed mineral manure, as plots 5, and 200lb. each sulphate and muriate of ammonia.

Plots 8 (*a* and *b*).—Mixed mineral manure, as plots 5, and 300lb. each sulphate and muriate of ammonia.

Plots 16 (*a* and *b*).—Mixed mineral manure, as plots 5, and 400lb. each sulphate and muriate of ammonia.

Plots 17 (*a* and *b*).—200lb. each sulphate and muriate of ammonia in the ninth and every alternate season; and mixed mineral manure, as plot 5, in every intermediate season.

Plots 18 (*a* and *b*).—Mixed mineral manure, as plots 5, in the ninth and every alternate season; and 200lb. each sulphate and muriate of ammonia in every intermediate season.

Plots 10 (*a* and *b*).—200lb. each sulphate and muriate of ammonia.

Plots 11 (*a* and *b*).—200lb. each sulphate and muriate of ammonia, and superphosphate of lime as plots 5.

Plots 12 (*a* and *b*).—200lb. each sulphate and muriate of ammonia, superphosphate of lime as plots 5, and 550lb. sulphate of soda (reduced to 366lb. in the sixteenth and subsequent seasons).

Plots 13 (*a* and *b*).—200lb. each sulphate and muriate of ammonia, superphosphate of lime as plots 5, and 300lb. sulphate of potash (reduced to 200lb. in the sixteenth and subsequent seasons).

Plots 14 (*a* and *b*).—200lb. each sulphate and muriate of ammonia, superphosphate of lime as plots 5, and 420lb. sulphate of magnesia (reduced to 280lb. in the sixteenth and subsequent seasons).

Plot 9*a*.—550lb. nitrate of soda and mixed mineral manure as plots 5 (only 475lb. nitrate in the ninth, and 275lb. in the tenth and eleventh seasons, and no mineral manure in the ninth, tenth, and eleventh seasons, commencing only in the twelfth).

Plot 9*b*.—550lb. nitrate of soda alone (only 475lb. in the ninth season).

Plot 15*a*.—Mixed mineral manure as plots 5 (but with 200lb. hydrochloric instead of 150lb. sulphuric acid), and 400lb. sulphate of ammonia.

Plot 15*b*.—Mixed mineral manure as plots 5 (but with 200lb. hydrochloric instead of 150lb. sulphuric acid), 300lb. sulphate of ammonia, and 500lb. rape cake.

Plot 19.—200lb. bone ash, 200lb. hydrochloric acid, 300lb. sulphate of ammonia, and 500lb. rape cake.

The sulphates of potash, soda, and ammonia, the muriate (chloride) of ammonia, and the nitrate of soda, were the ordinary articles of commerce passing under those names; the sulphate of magnesia was Epsom salts. The term "ammonia-salts" may for brevity be employed to denote the mixture of equal quantities of sulphate and muriate of ammonia.

The 14-acre field set apart for the experiments had, at the commencement of the investigations, grown turnips, barley, peas, wheat, and oats since the application of manure, and would therefore, according to the ordinary rules of practice, be considered so far exhausted as to need re-manuring before growing another crop. It was considered that a field in this condition would be peculiarly fitted to show in which of the constituents of the crop to be grown the soil had become practically the most deficient by the removal in rotation of the five preceding crops just enumerated. It was felt by the experimenters at the outset that far more had yet to be done in determining the chemical and physical qualities of soils in relation to the atmosphere, and to manurial substances exposed to their action, as well as in perfecting methods of analysis, before comparative analyses could aid much in deciding upon the relative productiveness of different soils, to say nothing of the still more difficult problem of estimating by such means the condition of fertility or exhaustion of one and the same soil at different times. The field was at first divided into plots, of which most consisted of two lands (each about 12ft. 5in. wide), running the whole length of the field, and comprising altogether nearly two-thirds of an acre. After the second season, however, the double land plots were each divided into two, though in most cases the two (*a* and *b*) were similarly manured, thus providing duplicate experiments with the same manure.

INFLUENCE OF SEASON ON THE WHEAT CROP.

In a series of forty tables are summarised the results of each season, every table showing for each plot the total weight of grain, and of straw and chaff, per acre, the number of bushels of dressed grain per acre, and the weight per bushel. In the first report the authors observe that no idea is more fixed and prevalent in the farmer's mind than that, after all his labour and money have been expended, he is still at the mercy of the seasons for his reward. The tables to which reference has just been made supply interesting evidence on this point, but the extent of the dependence upon season will be made more strikingly manifest by placing side by side the results obtained by one and the same description and amount of manure, in the least favourable and in the most favourable of the seasons during which the same manure has been supplied year after year on the same land. Of the twelve seasons during which, in the first twenty years, uniformity of manuring was maintained, the harvest of 1863 gave the best results, and that of 1853 the worst, and the authors compare these results in a table. Taking, however, the results also of the subsequent twenty years, whilst 1863 still occupies the best position, 1879 achieves the unpleasant notoriety of securing the worst, and it must suffice, therefore, to compare in Table I. the yields in these two years. The following are the numbers of the plots compared, with the description of manure per acre each received:

Plot.
3. Unmanured.
2. Farmyard manure.
5. Mixed mineral manure alone.
6. Mixed mineral manure and 200lb. ammonia-salts (= 43lb. nitrogen).

7. Mixed mineral manure and 400lb. ammonia-salts (= 86lb. nitrogen).
9. Mixed mineral manure and 550lb. nitrate of soda (= 86lb. nitrogen).
8. Mixed mineral manure and 600lb. ammonia-salts (= 129lb. nitrogen).

It is only by growing the same crop continuously for many years upon the same land, without any change in the conditions of manuring, that the influence of different seasons as so strikingly shown in this table, can be accurately ascertained. It is seen that, in the year 1863, the produce of the unmanured plots was 17¼ bushels; whereas, in the worst year, 1879, it was only 4¾ bushels. Nineteen unmanured crops had been grown previous to 1863, and the yield of that year was equal to the average of the first eight years. The unmanured yield of 1879, only 4¾ bushels per acre, was about one-third of the average yield of the plot during the whole period of forty years. Contrary to what might be expected, the produce on the land receiving farmyard manure, whilst it falls greatly in yield in a bad season, does not rise as rapidly in yield in a very favourable season. This is well illustrated by the following comparison: Plot 7, receiving mineral manures and ammonia-salts, gave in 1879 a crop practically equivalent to that of the farmyard manure plot (2), 16 bushels per acre; the average produce of the thirty-two years is almost identical in the two cases, one being 32¾, and the other 33½ bushels per acre. But in the favourable season of 1863, whilst the farmyard manure (plot 2) gave only 44 bushels per acre, the artificial manure (plot 7) gave 53⅝, being an excess of nearly 10 bushels per acre. It is therefore evident that, under the most favourable climatic circumstances, the artificial manure is capable of giving a much larger crop, both of grain and straw, than the farmyard manure. With the heaviest artificial manuring (plot 8), 35⅛ more bushels per acre of wheat, and upwards of two tons per acre more gross produce (grain and straw), were grown in the most favourable season, as compared with the produce grown by the same manures in the worst season.

The character of the weather during the best and worst

TABLE I.—SHOWING THE PRODUCE OF THE BEST SEASON, 1863, THE WORST SEASON, 1879, AND THE AVERAGE OF 32 YEARS, 1852-1883.

Dressed Grain, per Acre—Bushels.

Plot Nos.	Best Season, 1863.	Worst Season, 1879.	Difference	Average of 32 years, 1852-1883.
3	17¼	4¾	12½	13⅛
2	44	16	28	33½
5	19⅝	5⅝	14	15¼
6	39⅝	10½	29⅛	24⅛
7	53⅝	16¼	37⅜	32¾
9	55⅝	22	33⅝	36¼
8	55¾	20⅝	35⅛	36¼

Weight per Bushel of Dressed Grain—lb.

Plot Nos.	Best Season, 1863.	Worst Season, 1879.	Difference.	Average of 32 years, 1852-1883.
3	62·7	52·5	10·2	58·8
2	63·1	56·8	6·3	60·0
5	63·0	53·5	9·5	58·7
6	62·3	56·5	5·8	59·5
7	62·5	56·7	5·8	59·5
9	62·1	56·5	5·6	58·7
8	62·3	56·5	5·8	59·2

Straw (and Chaff) per Acre—lb.

Plot Nos.	Best Season, 1863.	Worst Season, 1879.	Difference.	Average of 32 years, 1852-1883.
3	1600	763	837	1272
2	4279	2239	2040	3570
5	1728	855	873	1464
6	3715	1592	2123	2512
7	5866	3012	2854	3771
9	6312	4347	1965	4688
8	6602	4176	2426	4532

Total Produce (Grain and Straw) per Acre—lb.

Plot Nos.	Best Season, 1863.	Worst Season, 1879.	Difference.	Average of 32 years, 1852-1883.
3	2727	1093	1634	2090
2	7165	3303	3862	5689
5	3017	1238	1779	2421
6	6243	2283	3960	4029
7	9358	4063	5295	5845
9	9888	5809	4079	6982
8	10,216	5527	4689	6832

seasons respectively is of considerable interest. The record for the season 1862-3 is as follows: October, unusually warm, but with a good deal of wind and rain; November, cold, comparatively little rain; December to February, unusually mild, with a fair amount of rain in December and January, and but little in February; March, upon the whole, mild, with but little rain, and wheat showing unusually forward growth; April, very dry and warm; May brought some refreshing rains, but temperature was occasionally extremely low, and pretty nearly throughout rather below the average, with frequent storms of wind; June, with temperature rather below the average, and with a good deal of rain, which, though needed, was so heavy as to lay the most forward and bulky crops; July brought much less rain than usual, with moderately high day but low night temperatures, and some sharp night frosts; August, with only moderate temperatures, but less rain than usual, was, upon the whole, favourable ripening anu harvesting weather; September was marked by a good deal of rain and rather low temperatures. In June the condition of the atmosphere as to moisture was about the average for that month, but in July, August, and September both the actual amount and the degree of humidity were below the average. The extraordinary yield of the harvest of 1863 would appear to have been due to the almost unchecked growth, from the first appearance of the plant above ground up to the time of harvest, rather than to any extraordinary characteristics of season at any one or more particular periods. With the extremely mild winter and early spring, the plant came early forward, and the rains, though sparing upon the whole, came when needed; whilst, though the temperature of the summer was seldom high, it was (excepting the night frosts of July) generally sufficient, and the condition of atmosphere otherwise favourable, so that the whole season contributed to a lengthened and almost unbroken course of gradual accumulation. The harvests of 1854 and 1857, in order, came nearest that of 1863 in total produce.

Turning now to the fateful season of 1878-79, the weather up to Oct. 21, 1878, was fine and warm; but it became cold and wet from Oct. 22 to Dec. 6, when severe frosts set in, and lasted till Dec. 26. There was, then, a good seed time, followed by intensely cold, wet weather, till nearly the end of the year, the temperature of the whole month of December being 6 degrees below the average. In 1879, January was one of the coldest months ever recorded, the thermometer standing below freezing point throughout; snow covered the ground, the days were nearly sunless, and the wind N. and N.E. February very cold, with a great excess of rain, and much snow. March first warm, then cold, with snow on the 21st; but the last days of the month warm. The five months ending March 31 were described as exceedingly cold, with much rain and snow. The next three months were cold, wet, and sunless; whilst, for lowness of temperature, the eight months ending with June, 1879, have only been once exceeded during the one hundred years and upwards which have elapsed since the first records were kept at Greenwich. July was dull, cold, and sunless; rain fell every day during the first half of the month, and frequently afterwards, sometimes mixed with snow. August was a very cold, wet month; there were a few warm days, during which no rain fell; and there were a few fine, dry days in the early part of September, after which rain fell almost daily until the end of the month. The wheat crop of 1879 was the worst grown in Great Britain since the year 1816. It was estimated that the crop of the country was not much more than half an average one.

If, from an examination of the results of the first twenty years' experiments on the continuous growth of wheat, an attempt be made to determine whether the latter or the earlier seasons were probably on the average the more favourable, the annual produce without manure would appear at first sight to afford the safest means of judging. A comparison of the tables showing the produce of each season serves to demonstrate, however, that those seasons which were the most favourable for the unmanured, or for the merely mineral-manured plots, were not at all the most favourable for those manured highly with nitrogenous fertilisers—that is, for those conditions under which alone large crops could be obtained. Hence, the best season for land in low condition is not the best for land in high condition.

But, by comparing the increasing or diminishing amounts of produce from year to year, under very different conditions of manuring, a very fair judgment of the relative character of

TABLE II.—AVERAGE ANNUAL PRODUCE (GRAIN AND STRAW) PER ACRE.

Plot.	Dressing every year.	First half of period.	Second half of period.	Total period.	Duration of total period.
		lb.	lb.	lb.	Years.
3	Unmanured	2711	2728	2719	20
10*a*	Ammonia-salts alone	4474	4166	4312	19
2	14 tons farmyard manure	4828	6355	5591	20
3	Unmanured	2641	2610	2626	12 (1852 to 1863).
5	Mixed mineral manure alone	3183	2927	3055	
10*a*	Ammonia-salts alone	4156	3921	4038	
7	Ammonia-salts and mixed mineral manure	6428	6546	6487	
2	14 tons farmyard manure	5896	6306	6101	

the earlier and later seasons can be formed. From a table indicating the average produce during the first half of the period, during the second half, and during the entire period, it appears that without manure a slightly, though very slightly, increased annual produce of grain and total produce (though not of straw) is marked over the last half as compared with the first half of the twenty years; with ammonia-salts alone there was a decreased, and with farmyard manure a very much increased, rate of produce in the later years. Table II. is a portion of the table referred to.

Thus, where the crop (plot 3) was simply dependent on the soil and season, the produce was somewhat higher in the later years; where the resources of the soil were overtaxed by the use of a large amount of ammonia salts every year (plot 10*a*), the produce diminished; but where an excess of every constituent was annually applied (plot 2) the crop enormously increased as the experiment proceeded. These generalisations are based upon the first three lines of figures in the foregoing table.

Taking the final twelve years, the table further shows that the average annual yield was, without manure (plot 3) much the same over the whole period; that, notwithstanding the exhausting effects of applying ammonia-salts every year (plot 10*a*), the annual diminution of produce under their influence was proportionally less during the latter half of the last twelve, than of the whole nineteen years of their use; that, where ammonia-salts and all mineral constituents, except silica, were liberally supplied every year (plot 7), the produce of grain increased and that of straw somewhat diminished; lastly, that where an excess of every constituent required by the crop was annually applied, as in the farm-yard manure (plot 2), the rate of increase from year to year was not so great during the later as during some of the earlier years.

Upon the whole, it must be concluded that the later years were, on the average, slightly more favourable to the crop than the earlier ones. The fact of the unmanured plot maintaining its produce throughout the whole twenty years is, then, probably in some degree due to the better average of the seasons themselves in the later years. Had it been otherwise, the unmanured produce would have shown some slight decline in the later years, or rather, some slight excess in the earlier ones, due to the accumulation of many previous courses of manuring and cropping. In the report of the second twenty years' experiments, and with the results of forty years' continuous growth before them, the investigators do not introduce a comparison between the first twenty years and the second twenty years so far as to determine which of the two periods was on the whole the more favourable for the growth of wheat. Nevertheless, the foregoing illustration will serve to convey an idea of the lines on which such an inquiry would be conducted.

EFFECTS OF THE UNEXHAUSTED RESIDUE OF MANURES.

Having, in the report of the first twenty years, discussed at length the amount and character of the produce obtained in different seasons, the authors proceed in a second section to inquire into the effects of the unexhausted residue from previous manuring (both nitrogenous and mineral) upon succeeding crops. The questions of the permanency of effect of different manures, and of the tendency to exhaustion which partial manuring may induce, are of great practical importance, and are frequently discussed by practical men. By means of a series of tables and coloured diagrams, a number of valuable conclusions are established, of which it is only possible to give here a summary.

It appears, then, that a somewhat heavy loam, of fair average wheat-producing quality, taken at the end of a five-course rotation since manuring, gave scarcely any increased produce of wheat in the year of the application, when manured with a mixture of silicate of potash and superphosphate of lime; but it gave a very considerable, though progressively diminishing, amount of increase, when afterwards manured for nineteen consecutive years with ammonia salts alone. Though, at the outset, the soil still contained an excess of annually available mineral constituents, as compared with the annually available nitrogen supplied by soil and season without manure, yet the annual application of large quantities of ammonia-salts made apparent the relative deficiency of mineral constituents, even as early as the fourth year. When ammonia-salts were applied, the greater portion of the nitrogen remained unrecovered as increased yield in the crop for which it was employed. The unexhausted residue of nitrogen supplied as manure was but very partially and very slowly recovered as increased yield in succeeding years, even when followed by the liberal application of such mineral manure as was very effective when used in conjunction with newly applied ammonia-salts. Mineral constituents supplied in the soluble condition in the fifth and seventh years of the experiments, though giving very little increase when in the latter year they were used alone, continued to increase the effect of ammonia-salts afterwards annually applied for thirteen consecutive years. A given amount of ammonia-salts gave very different amounts of increase, according to the supply of available mineral constituents within the soil, giving very much more when mineral manures were supplied in the same, than in the preceding year, notwithstanding that, in the latter case, there could be no deficiency, though, doubtless, less favourable condition and distribution of the mineral constituents. The same mineral manures which were very effective when supplied in conjunction with ammonia-salts, gave very little increase of produce when used alone year after year for twelve years, although following an excess of ammonia-salts applied in preceding years; and they gave very little more when they were applied every year succeeding an excess of ammonia-salts applied in the immediately preceding year. The unexhausted residue from previous mineral manuring, though it served as an effective reserve against exhaustion, had little or no effect in increasing the growth of wheat without the aid of available nitrogen provided within the soil. An unexhausted residue from previous nitrogenous manuring had also but little influence upon the immediately succeeding crops, even when aided by the application of mineral manures.

The bearing of the foregoing facts upon the question of the probable influence on the mineral wealth of our soils of the use of artificial nitrogenous manures, under the circumstances and in the degree in which they are generally employed in the ordinary course of agriculture in this country, remains to be considered. But it seems desirable to notice here what is said on the subject of the unexhausted residue of manures in the report of the second twenty years' experiments, for which the results obtained on plots 16*a* and 16*b* afford the necessary data. From 1852 to 1864 inclusive, these plots received mixed mineral manure and 800lb. of ammonia-salts per acre per annum, containing 172lb. of nitrogen. It is very rarely that a sufficiently large crop of wheat is grown to remove one-half of this quantity of nitrogen. In 1863 and 1864 the seasons were highly favourable for the growth of wheat; and, as the size of the crop is regulated very much by the amount of nitrogen at its disposal, the two seasons were well adapted for ascertaining how much of this very large application would be employed in the growth of the crop. In 1863, plot 16 gave 56 bushels per acre; in 1864, 51 bushels per acre. But plots 8*a* and 8*b* produced 56 bushels and 50 bushels in the same two years, by means of an application of 600lb. of ammonia-salts; and, as the additional 200lb. supplied to 16*a* and 16*b* only added one bushel to the crop, it was quite evident that the possible limits of growth on 8*a* and 8*b*, even in seasons so favourable, had been reached. All further manuring was, therefore, stopped after 1864, with the view of obtaining information, which might prove to be very valuable, in regard to the unexhausted residue of the manure employed.

Table III. shows the produce of plot 16 for the last two years during which it received manure, and for the nineteen succeeding years during which it was unmanured; also for comparison there is given the produce of plot 5, which received an annual dressing of minerals alone over the whole period.

It will be noticed that in the first year after the manures were stopped, the produce of plot 16 was 18 bushels more than that of plot 5. In the next year the difference was only 4 bushels in favour of plot 16. In each of the two next years plot 16 yielded 5 bushels in excess of plot 5. In the fifth year (1869) the total produce on plot 16, grain and straw, was only 104lb. more, and in the sixth year it was even 7lb. per acre less than on plot 5. During the next

TABLE III.

Year.	Dressed grain in bushels per acre.		Total produce (grain and straw) per acre, — lbs.	
	Plot 5. Minerals alone.	Plot 16. Minerals and 172lb. nitrogen.	Plot 5. Minerals alone.	Plot 16. Minerals and 172lb. nitrogen.
1863	19⅝	55⅞	3017	10,525
1864	16⅞	51⅛	2462	9348
		Unmanured		Unmanured
1865	14¼	32⅜	2091	5007
1866	13¼	17⅜	2303	3081
1867	9¼	14⅝	1613	2512
1868	17⅝	22¾	2481	3503
1869	15¾	16⅛	2543	2647
1870	18⅞	18¼	2564	2557
1871	11⅞	13½	2207	2380
1872	12¾	13⅛	2166	2387
1873	12¾	12¾	1806	1921
1874	13	11⅞	1674	1892
1875	9¼	10⅛	1714	1829
1876	10½	11	1429	1538
1877	11⅝	9⅞	1570	1340
1878	14¾	13⅝	2222	2181
1879	5⅝	4⅞	1238	1154
1880	17¾	14⅝	2818	2383
1881	12¾	13½	1709	1736
1882	12½	10¾	2057	1925
1883	15¾	15⅞	2147	2131

six years, however, the total produce of plot 16 exceeded that of plot 5 in amounts varying from 109lb. to 221lb. After 1876, the table shows that, with one exception, the yield on plot 16 was less than that on plot 5. It was, therefore, not until twelve years after the last application that all influence due to the previous manuring ceased.

The large crop grown in 1865, the first year after the manures were stopped, is attributed to some of the nitrogen of the salts of ammonia not having been washed out of the soil. The year of the last application, 1864, was one of exceptional drought—the driest experienced at Rothamsted during the whole forty years; it was probably owing to this that, at all events, a portion of the produce of the first year without manure was due. The excess of produce obtained on plot 16, as compared with plot 5, during the next eleven years, probably arose from the slow decay and nitrification of the stubble and roots of the very large crops which had been grown on this plot for so many years. During the thirteen years of the annual application of 800lb. of ammonia-salts, considerably more than 1000lb. of the nitrogen applied to the soil was not recovered in the crops. It is therefore hardly possible to suppose that the nitrogen (about 60lb.) contained in the 6663lb. of total produce obtained in excess of that grown on plot 5, during the next twelve years, could have been derived directly from that supplied as manure. excepting so far as a portion of that of the first crop was concerned. All the evidence, indeed, points to the residue of the crop itself as the source of the unexhausted manure; and it is quite certain that the very large amount of roots and other residue, possessing considerable fertilising influence, which some of our rotation crops leave in the ground, has much to do with their value as restorative crops. In 1865 samples of soil from various plots in the experimental wheat field were analysed, and the percentage of nitrogen in the first 9in. of soil was higher on plot 16 than on any other plot receiving artificial manures; whilst, in 1881, after seventeen unmanured crops had been taken, when the soil was again analysed, it was found that the percentage of nitrogen was considerably reduced, and it was in fact then not much higher than that on the continuously unmanured plot.

CONTINUOUS GROWTH OF WHEAT UPON THE SAME LAND FOR FORTY YEARS WITHOUT MANURE.

The third section of the report of the first twenty years' experiments is concerned with the average annual result over the last twelve years by each description of manure applied year after year on the same plot. As, however, the report of the second twenty years continues the same line of inquiry over a much longer period, it will suffice to glance at only one or two of the leading features given under this head in the first report. It is observed that an average annual produce of wheat, amounting to from 15 to 16 bushels of grain, and from 15 to 16 cwt. of straw, without manure of any kind, is looked upon by many as an extraordinary yield, and as indicating a somewhat unusual quality of land. There is no doubt it bears a higher proportion than might have been expected to the produce obtained, even under rotation with periodical manuring, in a large majority of cases where land is badly farmed; whilst deficient range and aeration of soil, luxuriant weed growth, and defective manuring, all contribute to the miserable result. The experimental land, though kept extremely clean, was not, however, ploughed more deeply than in the ordinary practice of the farm; and there can be little doubt that a large proportion of those soils of the country which are recognised as possessing average wheat-producing qualities would yield very similar results, if kept equally clean and otherwise as well cultivated; whilst some would, under like conditions, produce much more, though many light soils probably much less.

Regarding the history of the permanently unmanured plot over the two periods of twenty years each, it must be remembered that the last time this land received any manure was in 1839. The turnip crop of that year was succeeded by barley, peas, wheat, and oats, all unmanured, so that by

D 2

1844 the land might fairly be considered as, agriculturally speaking, exhausted. Since then the cultivation has been of the simplest description, and no attempt has been made to increase the crop by deep or subsoil ploughing; the land has, however, been kept free from weeds. A summary of the results, given in four periods of ten years each, is presented in Table IV.

TABLE IV.—PERMANENTLY UNMANURED PLOT.

	Dressed grain per acre.	Weight per bushel.	Total produce (grain and straw).
	Bushels.	lb.	lb.
Mean of 10 years, 1844-1853	15¾	58·25	2711
,, ,, 1854-1863	16½	57·57	2728
,, ,, 1864-1873	12¾	58·97	1924
,, ,, 1874-1883	10¼	58·25	1614
Mean of 40 years	14	58·26	2244

The increased yield of grain during the second ten years as compared with the first is attributed to the favourable seasons of the second decade; the total produce (grain and straw), a much more accurate measure of the available fertility of a soil than is the grain alone, is also slightly higher over the second period than over the first. The decline during the third decade as compared with the second is seen to be very marked, much more so than that of the fourth as compared with the third. But the more recent seasons had been so unfavourable for the growth of wheat that the produce of the fourth ten years cannot be accepted as correctly representing the reduction due to soil exhaustion alone. This is proved by the fact that the produce of the last year, 1883, in a rather better season, was 13¾ bushels per acre, which closely approximates to the average yield of the forty crops.

The annual decline in the produce, due to exhaustion—

irrespective of variations due to good or bad seasons—is, probably, up to a certain period, equivalent to about a quarter of a bushel per acre per annum, representing a gross produce in grain and straw of 40lb. per acre. But, with each decline, the reduction must obviously become less and less; atmospheric influences, and even the small amount of ammonia brought down in the rain, will produce a great effect upon a declining crop. Hence, the actual process of the exhaustion of the soil differs considerably from all the preconceived ideas on the subject. The soil, in fact, not only contains more fertility, but also holds it with a much firmer grasp, and parts with it less readily, than was previously thought to be the case.

The average annual amount of total produce (grain and straw) removed has been 1 ton per acre, containing nearly 1900lb. of absolutely dry matter; and there is strong evidence, derived from other experiments in the field, to prove that the carbon, indeed a large proportion of the organic matter, is derived from the atmosphere, whilst the nitrogen and the mineral matter are taken from the soil. This would divide the products into from 94 to 95 per cent. atmospheric constituents (including water), and from 5 to 6 per cent. soil constituents. The average amount of soil constituents (minerals and nitrogen) annually removed by this unmanured wheat crop is from 100lb. to 120lb. per acre; and of the three most important constituents of plant growth there have been removed about 17lb. of potash, 10lb. of phosphoric acid, and 20lb. of nitrogen.

It appears, then, that upon a field which has been under arable cultivation certainly for two or three centuries—and possibly for a much longer period—and which has consequently lost a very considerable amount of its original fertility, there is—after the removal of forty unmanured crops—a yield which differs very little from the average of some of the great wheat-growing countries of the world; the yield of the United States, India, and China being, it is stated, from

12 to 13 bushels per acre. As the Rothamsted soil certainly contains a very much less stock of fertility than the soils upon which wheat is extensively grown in other countries, it is impossible to attribute the comparatively large yields there to any other cause than to the clean state of the land. The amount of food at the disposal of the crop is small, but it is not shared to any great extent with other plants. The large produce of both wheat and barley on the unmanured land in the Woburn experiments also shows how much the crops grown upon the ordinary cultivated land of this country are reduced by weeds. It is true that weeds do not exhaust a soil, as, in their decay, the fertility which they have taken up becomes again available; but they take up nitrates, which, during their growth, revert to the form of organic nitrogen (that is, nitrogen combined with carbon), and this must undergo nitrification in the soil before becoming again available as plant food. Considering the high price paid for active nitrogen, as in salts of ammonia or nitrate of soda, a serious loss is incurred if this nitrogen goes to promote the growth of weeds, as so much time must elapse before it is again available as food for a future crop.

CONTINUOUS GROWTH OF WHEAT UPON THE SAME LAND WITH MINERAL MANURES ALONE.

The plot which received mineral manures alone next claims consideration. Bearing in mind the fact that uniformity of manuring was not resorted to on all the plots till after the expiration of eight years, the remaining thirty-two years of the total forty may be conveniently divided into four periods of eight years each. In Table V. the corresponding results on the unmanured plot are given for the sake of comparison.

During the first eight years (1844-1851) plot 5 received ammonia-salts as well as mineral manures, and the average yield during those eight seasons was 29 bushels per acre, or nearly 12 bushels annually in excess of the produce on the unmanured plot; whilst during the first eight years of the mixed minerals, without the ammonia-salts (1852-1859), the average produce was 19 bushels per acre, or about 3 bushels more than the permanently unmanured produce. Comparisons respecting subsequent periods are afforded by the table, and it will be seen that, whilst the

TABLE V.—SHOWING THE AVERAGE PRODUCE OF DRESSED GRAIN, AND TOTAL PRODUCE (GRAIN AND STRAW) PER ACRE ON PLOT 3 (PERMANENTLY UNMANURED), AND PLOT 5 (RECEIVING MIXED MINERALS FOR A PERIOD OF THIRTY-TWO YEARS), OVER FOUR PERIODS OF EIGHT YEARS EACH, AND OVER THE TOTAL PERIOD.

	Dressed grain.		Total produce (grain and straw).	
	Without manure. Plot 3.	Mixed minerals. Plot 5.	Without manure. Plot 3.	Mixed minerals. Plot 5.
	Bushels.	Bushels.	lb.	lb.
8 years, 1852-1859	16⅛	19	2736	3191
" 1860-1867	13½	15¼	2183	2450
" 1868-1875	12¼	14	1833	2144
" 1876-1883	10½	12⅝	1610	1899
32 years, 1852-1883	13⅛	15¼	2090	2421
40 years, 1844-1883	14	—	2244	—

average produce of the unmanured plot for forty years was 14 bushels, the average of thirty-two years for the plot receiving mixed minerals was 15¼; hence the application of a very liberal supply of minerals has only been competent to increase the yield by 1¼ bushels per acre per annum! Again, the average total produce for the thirty-two years shows a difference of only 331lb. in favour of the minerals. The amount of nitrogen in this 331lb. would not exceed 3lb., and this represents the whole of the nitrogen which the wheat upon an acre of land, though furnished with an abundance of minerals, and certainly at the commencement containing more crop residue than the unmanured land, has been able to obtain from the soil and the atmosphere in excess of that in the wheat grown without manure!

The history of these plots 3 and 5 is very instructive. Their yields year by year rarely differ from each other by more than from 3 to 4 bushels per acre. The yield on both is slowly declining, and for the last twenty-four years neither has given as much as 20 bushels per acre; and, without some change in the manures, it is hardly likely this amount can ever be grown again. The soil contains a large amount of the mineral food of plants; it also contains organic nitrogen—that is, nitrogen combined with carbon, the residue of previous vegetation. This organic nitrogen is not directly available as food for the wheat plant, but every year a certain portion of it is converted into nitric acid, which combines with the lime in the soil. In this state it is very soluble in water, is readily washed out of the soil by heavy rain, and is a most important and essential food of the wheat plant. The amount of nitric acid formed each year will vary, the process of nitrification being most rapid in the hottest weather, provided the soil is sufficiently moist. The amount of nitric acid which the wheat crop can take up will also vary, and in a cold and wet winter much will be washed beyond the reach of the roots of the plant. These facts are of universal application, and by them it is possible to explain some of the causes which tend to the production of good or bad crops of wheat. Analysis proves both plots 3 and 5 to have lost a large amount of organic nitrogen, and that, in the first nine inches' depth, the mineral-manured soil has lost rather the more. The total loss of nitrogen over a given area is larger than the amount of that substance removed in the crops, and the reason is that, except when the crop is in full vigour of growth, the drainage waters contain nitric acid. Of the 28lb. to 32lb. of nitrogen per acre available each year at

Rothamsted, from soil, seed, rain, &c., only about two-thirds are removed in the crop, whilst one-third goes into the drains and is lost. The experiments under discussion provide an explanation of the fact that on some soils—more especially the newly cultivated soils of the United States and of Canada —a large increase in the wheat crop frequently follows the application of mineral manures. Soils rich in organic matter may yield an increased amount of nitric acid by the application of phosphates and potash, but in all cases the source of the nitrogen is the soil; and the loss by the unmanured soil of perhaps from 800lb. to 1000lb. of nitrogen per acre during the forty years of these experiments is a fact of the greatest importance.

CONTINUOUS GROWTH OF WHEAT UPON THE SAME LAND WITH AMMONIA-SALTS ALONE.

Leaving the mineral-manured plot, the next subject to study is the produce of plots 10*a* and 10*b* (ammonia-salts without minerals), and plots 17 and 18 (ammonia-salts in alternation with minerals). Recent legislative enactments, giving the cultivator of the soil a claim for the manure ingredients possessing a pecuniary value, which he has applied and left in the land, add greatly to the interest of this and allied investigations. The difference between the plots 10*a* and 10*b* is that 10*a* received one dressing of minerals followed by thirty-nine dressings of salts of ammonia, whereas 10*b* received three dressings of minerals in the course of the first seven years, since when both plots have been treated exactly alike. Table VI. indicates (1) the produce of each plot in each of the first eight years; (2) the average produce over succeeding periods of eight years each; (3) the average produce over thirty-two years. To be precise, it should be stated that 10*b* received minerals alone in 1844 and 1850, was unmanured in 1846, received minerals with ammonia-salts in 1848, and ammonia-salts alone (like 10*a*) in 1845, 1847, 1849, 1851, and in each of the last thirty-two years; 10*a* received mineral manure alone in 1844, and ammonia-salts alone in each of the last thirty-nine years.

TABLE VI.—AMMONIA-SALTS ALONE.

	Dressed grain.		Total produce (grain and straw).	
	Plot 10*a*.	Plot 10*b*.	Plot 10*a*.	Plot 10*b*.
	Bushels.	Bushels.	lb.	lb.
1844	15$\frac{1}{2}$	15$\frac{1}{2}$	2120	2120
1845	31$\frac{7}{8}$	31$\frac{7}{8}$	6246	6246
1846	27$\frac{3}{8}$	17$\frac{5}{8}$	4094	2671
1847	25$\frac{3}{4}$	25$\frac{3}{4}$	4593	4579
1848	19$\frac{1}{4}$	25$\frac{1}{8}$	3701	4530
1849	32$\frac{5}{8}$	32$\frac{3}{8}$	4992	5117
1850	27	18	4810	3120
1851	28$\frac{7}{8}$	28$\frac{5}{8}$	5036	4985
8 years, 1852—1859 ...	22$\frac{3}{4}$	27$\frac{1}{2}$	4055	4885
„ 1860—1867 ...	24	27$\frac{1}{4}$	4076	4563
„ 1868—1875 ...	19	20$\frac{1}{8}$	3060	3264
„ 1876—1883 ...	16$\frac{3}{8}$	18$\frac{1}{8}$	2618	2935
32 years, 1852—1883 ...	20$\frac{1}{2}$	23$\frac{1}{4}$	3452	3912

Of the period preceding 1852, in the season of 1848, 10*b* received mineral manures, as well as ammonia-salts, and yielded 25$\frac{1}{8}$ bushels per acre, as against 19$\frac{1}{4}$ bushels on 10*a*, which received the same ammonia-salts without minerals. On the other hand, when 10*b*, in 1850, received minerals alone, the produce was only 18 bushels per acre, as against 27 bushels obtained on 10*a*, manured with ammonia-salts only. Though, in the periods of eight years, the produce of 10*b* is always in excess of that of 10*a*, the difference is nevertheless seen to be a declining one. As the drainage water from cultivated fields is known to contain but a very small amount of potash, and frequently no phosphoric acid, there is no difficulty in tracing the increased produce obtained on 10*b* over 10*a* to the minerals applied to the former in 1848 and 1850. These large applications of potash and phosphoric acid, although in the form of soluble compounds, appear to enter into very fixed combinations, somewhat similar to those already existing in the soil, and in this respect they differ altogether from compounds of nitric acid and ammonia, as the latter appear to be either washed away or destroyed, unless they are fixed by vegetation, whilst the former are fixed by the soil itself, and are only taken out of it by means of vegetation.

CONTINUOUS GROWTH OF WHEAT UPON THE SAME LAND WITH AMMONIA-SALTS AND MINERAL MANURES IN ALTERNATING YEARS.

The experiments on plots 10*a* and 10*b* show that potash and phosphoric acid were still producing an influence upon the wheat crop thirty-three years after their application. Turning now to plots 17 and 18, it will be possible to trace the unexhausted residue of another substance perfectly soluble in water namely, salts of ammonia. On these plots the mineral manures and the ammonia-salts are never used together. When plot 17 receives minerals, plot 18 receives ammonia-salts, and when plot 18 receives minerals, plot 17 receives ammonia-salts. Therefore, during the thirty-two years, each plot received sixteen applications of mineral manures and sixteen applications of ammonia-salts. For the crops of the first eight years (1844-1851) the two plots received different artificial manures, yielding a very similar produce. Table VII. records the average produce of the mineral manures, and also of the ammonia-salts over four periods of eight years each, and, for comparison, the average produce on plot 5, receiving minerals alone, is given.

The bottom line, giving the average of the entire thirty-two years, is wonderfully instructive. It shows that during the sixteen alternate seasons in which plot 17 received ammonia-salts, and the sixteen alternate seasons in which plot 18 received that substance, the average produce was 30 bushels per acre, whilst during the alternate years, in which the plots received minerals only, they yielded but $15\frac{5}{8}$ bushels; or, in other words, only a fraction more than plot 5, which received no ammonia-salts during the whole period. It is estimated that the 400lb. of ammonia-salts applied per acre contain 86lb. of nitrogen, but the resources

TABLE VII.—AMMONIA-SALTS COMPARED WITH MINERALS.

	Dressed grain per acre.			Total produce (grain and straw) per acre.		
	Mineral manures only every year. Plot 5.	Mineral manures. Plots 17 or 18.	Ammonia-salts. Plots 17 or 18.	Mineral manures only, every year. Plot 5.	Mineral manures. Plots 17 or 18.	Ammonia-salts. Plots 17 or 18.
	Bushels.	Bushels.	Bushels.	lb.	lb.	lb.
8 years, 1852-1859 ...	19	$18\frac{7}{8}$	$32\frac{3}{8}$	3191	3235	5938
" 1860-1867 ...	$15\frac{1}{4}$	$16\frac{1}{2}$	$31\frac{1}{4}$	2450	2696	5297
" 1868-1875 ...	14	15	$28\frac{1}{2}$	2144	2404	4781
" 1876-1883 ...	$12\frac{5}{8}$	$12\frac{1}{4}$	$27\frac{3}{4}$	1899	1869	4930
32 years, 1852-1883...	$15\frac{1}{4}$	$15\frac{5}{8}$	30	2421	2551	5237

of the soil were evidently competent to furnish the nitrogen contained in 15 bushels of wheat and its straw, inasmuch as plot 5, receiving no ammonia, gave that produce. In the additional 15 bushels and its straw obtained by the application of the ammonia-salts, certainly less than 26lb. of nitrogen are carried off, thus leaving 60lb. of nitrogen per acre to be accounted for. Although analysis proved that, in 1881, the soil of plots 17 and 18 contained rather more total nitrogen and nitrates than plot 5, still, to a depth of as much as 27in. there was no evidence of the existence in the soil of the large amount of nitrogen supplied in the manure, and not accounted for in the crop. Hence, when ammonia-salts are applied to grow wheat, it is not safe to calculate upon any of the unexhausted residue being available for the purpose of growing a second corn crop. The evidence also indicates that the exhausting character which farmers attribute to corn crops is quite as much due to the nitrogen which they do not assimilate being washed out of the soil, as it is to the amount of that substance which is removed in the produce.

COMPARISON BETWEEN AMMONIA-SALTS AND NITRATE OF SODA AS SOURCES OF NITROGEN.

One other series of experiments with artificial manures remains to be discussed. The results already considered are those of experiments in which mixed minerals alone, or salts of ammonia alone, are employed. It is necessary now to notice those in which one uniform quantity of mixed minerals is used in each case, but with different amounts of nitrogen in the form of ammonia-salts, and also as nitrate of soda. The nitrogenous applications were as follows: Plots 6*a* and 6*b*, 200lb. of sulphate and muriate of ammonia, containing 43lb. of nitrogen; plots 7*a* and 7*b*, 400lb. of the same salts, containing 86lb. of nitrogen; and plots 8*a* and 8*b*, 600lb. of the same salts, containing 129lb. of nitrogen; whilst plot 9*a* received 86lb. of nitrogen as nitrate of soda, instead of as ammonia-salts. Table VIII. is drawn up on the same principle as the preceding tables, and similarly records the result in four periods of eight years each.

It is apparent that in the separate periods of eight years each, and also in the whole period of thirty-two years, the increase of wheat obtained by adding 43lb. of nitrogen (plot 6) to the minerals varies from 8 to 11 bushels per acre, the total increase over the whole period being not quite

9 bushels per acre. The addition of another 43lb. of nitrogen (plot 7) again increases the amount of wheat by between 8 and 9 bushels over the whole period, as compared with plot 6, receiving only half as much nitrogen. The addition

TABLE VIII.—AMMONIA-SALTS COMPARED WITH NITRATE OF SODA.

Dressed Grain, per Acre—bushels.

	Mixed minerals alone. Plot 5.	Mixed mineral manures and ammonia-salts.			Mix, min. manures & nitrate of soda.
		= 43lb. nitrogen. Plot 6.	= 86lb. nitrogen. Plot 7.	= 129lb. nitrogen. Plot 8.	= 86lb. nitrogen. Plot 9.
8 years, 1852—1859 ...	19	27⅞	35½	36⅞	31⅛
,, 1860—1867 ...	15¼	26¼	36¼	39¾	40¼
,, 1868—1875 ...	14	22	31	36	39
,, 1876—1883 ...	12⅝	20⅜	28	32¼	34¾
32 years, 1852—1883 ...	15¼	24⅛	32¾	36¼	36¼

Total Produce (Grain and Straw) per Acre—lbs.

	Mixed minerals alone. Plot 5.	Mixed mineral manures and ammonia-salts.			Mix. min. manures & nitrate of soda.
		= 43lb. nitrogen. Plot 6.	= 86lb. nitrogen. Plot 7.	= 129lb. nitrogen. Plot 8.	= 86lb. nitrogen. Plot 9.
8 years, 1852—1859 ...	3191	4808	6490	7012	5897
,, 1860—1867 ...	2450	4276	6262	7363	7862
,, 1868—1875 ...	2144	3612	5379	6593	7344
,, 1876—1883 ...	1899	3422	5248	6361	6824
32 years, 1852—1883 ...	2421	4029	5845	6832	6982

of a third 43lb. of nitrogen (plot 8) proved far less effective than the previous additions, as, instead of being from 8 to 9 bushels, the average increase was only 3½ bushels per acre; the average of the whole period being, for the 129lb. nitrogen,

$36\frac{1}{4}$ bushels per acre, whilst where 86lb. of nitrogen was applied it was only $3\frac{1}{2}$ bushels less. The total increase obtained by this large amount of nitrogen (129lb.), in excess of the produce obtained by minerals alone, amounted only to 21 bushels per acre per annum; hence it is clear that in this experiment the nitrogen applied was in excess of the quantity which could be utilised by the crop; and even in the best season of growth, 1863, when plot 7, receiving 86lb. of nitrogen, yielded $53\frac{1}{2}$ bushels per acre, the plot receiving 129lb. only yielded 2 bushels more!

Some important practical inferences are now deducible. Sir John Lawes and Dr. Gilbert estimate the average yield of wheat in Great Britain at 28 bushels, while others put it at 30 bushels per acre. The crop obtained by 86lb. of nitrogen appears to have quite reached, if it has not exceeded, the profitable limit of growth, and only a rise in the price of wheat—and not lower prices—could justify the outlay in manure which would be required to grow a larger crop. Much of the nitrogen of the ammonia-salts has been converted into nitric acid, and washed into the drains, chiefly during the winter. At the time of applying the nitrate of soda in the spring, the plots receiving ammonia-salts in the autumn had already lost more or less nitrogen; and until 1878 the trial of the relative crop-producing power of nitrogen as ammonia, and as nitric acid in the form of nitrate of soda, was not carried out on equal terms. For the crops of 1878-83 plots *7a* and *7b* received the ammonia-salts in the spring, whilst another plot similarly manured received these salts in the autumn; and, although the spring-sown ammonia has given the largest produce, still, the difference between the two crops is by no means what might have been expected from the known loss by drainage which took place when the manure was autumn-sown, so that the question arises whether there has been loss by destruction and evolution of free nitrogen, or whether any considerable amount of the ammonia has remained unnitrified in the soil, which would be in a much drier state in the spring and summer than during the autumn and winter.

From the table it may be seen that it was not until after the experiment had been carried on for eight years that the spring-sown nitrate showed a superiority over the autumn-sown ammonia-salts; but during the first three years there were no minerals, and there was much less nitrate, applied to the nitrate plot (9*a*). During the next three periods of eight years each, the produce by the nitrate was considerably in excess; though in six of the last eight years the ammonia-salts were applied in the spring. Over the thirty-two years the nitrate gave an increase over the ammonia-salts, containing an equal quantity of nitrogen, of 3½ bushels per acre per annum (36¼ bushels as against 32¾). Another noteworthy feature is, that the spring-sown nitrate supplying 86lb. of nitrogen gives exactly the same total average yield (36¼ bushels) as the chiefly autumn-sown ammonia-salts supplying 129lb.; and, taking the total produce (grain and straw), which is by far the best measure of the power of a manure to promote growth, it is seen that the 86lb. of nitrogen as nitrate of soda produced 6982lb., whilst the 129lb. of nitrogen as ammonia-salts produced 6832lb. Although there is often a strong prejudice against the use of nitrate, this experiment shows that, when judiciously applied, its properties as a manure are superior to those of ammonia-salts. When used continuously for thirty-two years, its power to produce growth appears to increase rather than to diminish; as during the last sixteen years the total produce per acre per annum of plot 9*a* in excess of the produce of plot 7—each receiving the same amount of nitrogen—has been 7084lb. as against 5313lb., a difference of 1771lb. in favour of the nitrate.

CONTINUOUS GROWTH OF WHEAT UPON THE SAME LAND FOR FORTY YEARS WITH FARMYARD MANURE SUPPLIED EACH YEAR.

When a plot of land which has grown wheat continuously for forty years has every year received a dressing of farmyard manure, the lessons to be learnt from an examination of the results cannot but commend themselves as eminently deserving the attention of agriculturists. Plot 2 in the experimental wheat-field at Rothamsted is such a plot, and for the last forty years it has annually received ordinary farmyard manure at the rate of 14 tons per acre. No attempt was made to ascertain the exact composition of the manure applied, for two reasons: (1) in the earlier years of the experiments, the importance of knowing the exact amount of the various ingredients applied to the soil was not well understood; (2) later on, the uncertainty of the results obtained in a very careful attempt to ascertain the exact composition of some box-dung at Woburn made it apparent that it would be preferable to trust to an estimate of the composition based on numerous analyses of farmyard manure. Table IX. gives the estimated amount of some of the more important ingredients supplied to the soil of plot 2 annually in the 14 tons farmyard manure, as also the amount of ingredients supplied in the artificial manure on plot 7, which receives mixed minerals and 400lb. of ammonia-salts per acre.

TABLE IX.

	Dry organic matter.	Nitrogen.	Phosphate of lime.	Potash.
	lb.	lb.	lb.	lb.
Farmyard manure, plot 2	8540	200	155	168
Artificial manure, plot 7	—	86	140	100*

* 150lb. 7 years, 1852-8, 100lb. each year since.

Although the ingredients furnished to the two plots differ widely, the average produce is nevertheless almost the same on each, as is clearly shown in Table X.

TABLE X.—FARMYARD MANURE (Plot 2) AND ARTIFICIAL MANURE (Plot 7) COMPARED.

	Dressed grain per acre—bushels.		Total produce (grain and straw) per acre—lbs.	
	Plot 2.	Plot 7.	Plot 2.	Plot 7.
8 years, 1852-1859	34⅜	35½	6100	6490
„ 1860-1867 ...	35¾	36¼	5926	6262
„ 1868-1875	35¼	31	5932	5379
„ 1876-1883	28⅝	28	4798	5248
32 years, 1852-1883......	33½	32¾	5689	5845
40 years, 1844-1883, with farmyard dung	32⅜	—	5516	—

Taking the whole thirty-two years, the difference in the average produce per acre per annum is seen to be less than one bushel of grain—in fact, only three-quarters of a bushel. Of total produce, grain and straw, the mixed minerals and ammonia-salts on plot 7 gave an increase over the farmyard manure on plot 2, over the same period, of 156lb. per acre per annum. The most striking contrast between these two manures, which furnish almost identical results, is that whilst the farmyard manure supplies to the soil a large amount of organic matter, the artificial manure supplies none. Each year plot 2 received in the farmyard manure about 8540lb. of organic matter, whilst the crop grown upon it would not contain more than one-half this quantity. Yet the artificial manures on plot 7, supplying no organic matter whatever, produced a crop which contained rather the larger amount of organic matter of the two; and it can be shown that, by merely increasing the amount of nitrogen, a still larger amount of organic matter can be obtained in the crop. Thus plot 8, receiving 129lb. of nitrogen per annum (still much less than that supplied in the farmyard manure) gave, over a period of thirty-two years, a total produce, grain and straw, of 6832lb. per acre, or 1143lb. more than that obtained by the farmyard manure on plot 2. Hence, it is concluded, the amount of non-nitrogenous (chiefly carbonaceous) organic matter in the crop bears no relation to that supplied in the manure; the atmosphere, and not the soil, is the source of this supply.

In the two years 1863 and 1864 the farmyard manure applied to plot 2 was estimated to furnish 400lb. of nitrogen, and the total produce was 13,653lb.; whilst that of plot 16, which received only 344lb. of nitrogen, in ammonia-salts, was 19,873lb. There were, therefore, in the two years, 6220lb. excess of crop on the artificially manured plot. The nitrogen, then, of farmyard manure and that of ammonia-salts, or of nitrate of soda, must obviously be in different states of chemical combination. This indeed is so, for in the dung the nitrogen is mostly combined with carbon, in which form it is both insoluble and inactive, and, for most crops, at any rate, it only becomes available when, by the process of nitrification, it ceases to be in combination with carbon, and passes into the form of a soluble nitrate. Nitrate of soda contains nitrogen in this form, and this is the reason it is so immediately available to a growing crop, and becomes speedily lost in the drainage water if there is not a growing crop ready to make use of it. The time required for the nitrification of different portions of farmyard manure will be very variable; the carbon may be separated from the nitrogen in urine in a very short time, whilst it may take many years to nitrify portions of the nitrogenous organic matter of straw, especially on heavy land. Since it requires a considerably larger application of nitrogen in the form of farmyard manure to grow the same amount of crop as that produced by a much smaller application of nitrogen in the more active form of ammonia-salts, or nitrates, it follows that in the soil where dung has been employed there ought to be found a larger amount both of carbon and of nitrogen than in the soil where artificial manures have been used. It is indeed an ascertained fact that, to *accumulate* nitrogen in the soil, it must be in combination with carbon, though very little is yet known in regard to the various compounds of carbon existing in the soil. But, respecting the subject now under discussion, the evidence as to the underground fertility of plots 2, 3, and 7, as brought out in the analyses of their soils to various depths, is both interesting and instructive. It is estimated that, within 27in. from the surface, the nitrogen on plot 2 (farm-yard manure) will amount to more than 8000lb. per acre, and that it would exceed the amount on plot 7 (mixed minerals and ammonia-salts) to the same depths by more than 1700lb., and that on plot 3 (permanently unmanured) by more than 2200lb. By far the largest amount of this difference is found in the first 9in. of depth; to that depth the dunged land contained nearly double the amount of nitrogen which is found on the unmanured plot, and more than one and a half times as much as is found on the plot receiving minerals and ammonia-salts; and it is estimated that plot 3, after the removal of forty unmanured crops of wheat in succession, still contains about 2400lb. of nitrogen per acre in the first 9in. from the surface; this, in fact, represents the residue of the natural fertility, or, to use a term imported into the Agricultural Holdings Act, the inherent capability of the soil.

The relation between the carbon and nitrogen in these three soils, which differ so greatly in their total amounts of nitrogen, indicates that they do not differ much in their character. On the unmanured land there is not quite ten of carbon to one of nitrogen; on plot 7, receiving minerals and ammonia-salts, it is ten and a half to one; on the dunged land it is not quite twelve to one. Yet the unmanured plot has received neither carbon nor nitrogen in manure; plot 7 has received a very large amount of nitrogen, but no carbon; whilst the dunged plot has received a very large amount of both carbon and nitrogen. The relation of carbon to nitrogen in the farmyard manure is about twenty to one—a proportion totally different from that in the soil. The close relation between the carbon and nitrogen, in the soils of plots 3 and 7, indicates that the larger amount of nitrogen in plot 7 is not due to the direct storing up of ammonia by the soil, but to the nitrogen forming part of the vegetable growth, and being thus stored up in the stubble and roots. If the nitrogen of the ammonia-salts had been stored up in any form except that of vegetable growth, the relation of carbon to nitrogen would have been lower on plot 7 than on plot 3, instead of which it is higher; there is also proof founded on analyses of the soils of plot 7 and plot 3 that, of the two, the latter contains by far the larger amount of unexhausted fertility.

The adjoining field, where barley is grown continuously, furnishes similar evidence. For twenty consecutive years, 14 tons per acre of farmyard manure were applied to one plot of barley, after which period the plot was divided into two, the dung being continued on the one half, and stopped on the other. Up to 1883, twelve unmanured crops had been taken, yielding an average of 34½ bushels per acre, and, as the last of these crops, in the rather favourable season of 1883, exceeded 35 bushels, there is evidence of a long future before the fertility due to the residue of the twenty years' application of dung will be exhausted. In the same field the plots manured with rapecake yield on analysis a considerably larger amount of nitrogen than any of the plots where minerals, or minerals with ammonia-salts or nitrate, have been used. It follows that whilst fertility may be stored up in the soil, in the form of such mineral substances as potash or phosphate, it does not appear that the more valuable substance, nitrogen, can be stored up unless combined with carbon; in other words, whilst the soil fixes potash and phosphoric acid independently of vegetation, nitrogen is only fixed by the agency of vegetation.

QUANTITY OF AMMONIA REQUIRED TO PRODUCE AN INCREASE OF ONE BUSHEL PER ACRE IN THE WHEAT CROP.

One important point remains for discussion. It constitutes the subject of the fourth section of the report of the first twenty years' experiments, and deals with the amount of increased produce obtained for a given amount of ammonia supplied in manure. The data are furnished in Table XI., which shows the annual average amount of ammonia in manure (or of nitrogen as nitrate, reckoned as ammonia) that was required for the production of one bushel (of 60lb.) increase of wheat grain, with its proportion of straw, on the most important plots, in two periods of six years each, and in the total period of twelve years; in two or three cases there were some modifications made in the manures, but, to avoid complicating the table, these are not introduced.

Long before the expiration of the first twenty years of the wheat experiments, the investigators published their opinion, founded on experiment, that the grower might assume, for practical purposes, that he would, on the average of seasons, get one bushel of wheat and its proportion of straw, beyond the produce of the soil and season, for each 5lb. of ammonia applied in the manure for the crop. The results shown in Table XI. confirm this opinion. 50lb. of ammonia, or its equivalent of nitrogen, would be supplied in rather under 2cwt. of commercial sulphate of ammonia, or in $1\frac{3}{4}$cwt. of commercial muriate of ammonia, or in about $2\frac{3}{4}$cwt. of genuine Peruvian guano, or in rather more than $2\frac{1}{4}$cwt. of nitrate of soda. These amounts are more than are usually employed in common practice for the wheat crop, and most growers would consider double these quantities to be very heavy, if not excessive, dressings. Assuming that the results obtained by the use, per acre, of 50lb. or 100lb. of ammonia (or their equivalent of nitrogen in nitrate of soda) most nearly represent those which may be expected in ordinary practice, and, further, that the results obtained by these amounts in the cases where the mineral constituents (unless silica) are not in relative defect are also such as are most likely to be obtained in ordinary farm practice, the authors subject the tabulated results to a thorough examination. The figures show how very striking is the difference

TABLE XI.

Plots.	Manures per acre per annum, for 12 years, 1852-1863.	Average quantity of ammonia required to produce one bushel (=60lb.) increase in wheat crop.		
		First 6 years. 1852-57.	Second 6 years. 1858-63.	The 12 years 1852-63.
		lb.	lb.	lb.
6	200lb. amm.-salts, and mixed min. manure	5·59	4·36	4·86
7	400lb. „ „ „	5·86	4·95	5·37
8	600lb. „ „ „	8·01	6·80	7·35
16	800lb. „ „ „	9·98	9·00	9·47
17 or 18	400lb. amm.-salts, in alternation with mixed mineral manure	6·92	6·47	6·69
10*a*	400lb. amm.-salts alone (19 yrs. 1845-63)	20·52	22·74	21·57
10*b*	400lb. „ „ (13 yrs. 1851-63)	10·39	12·16	11·20
11	400lb. „ and super-phosph. of lime	8·92	8·25	8·57
12	400lb. „ and super-phosph., and sulphate of soda ...	6·39	5·24	5·76
13	400lb. „ and super-phosph., and sulphate of potash..	6·58	5·27	5·85
14	400lb. „ and super-phosph., and sulphate of magnesia	6·31	5·31	5·77
9*a*	550lb. nitrate of soda and mixed min. man.	6·59	4·73	5·41
9*b*	550lb. „ alone.....................	11·29	14·73	12·80

of effect upon the immediate increase of a given amount of nitrogen in manure, whether used in the form of ammonia-salts or of nitrate, according to the available supply of mineral constituents in the soil. With the overwhelming evidence before him which such a comprehensive summary of experimental results on the point affords, the grower cannot fail to see that he not only very injuriously further reduces his immediately available supply of mineral constituents, but also pays very dearly for his increase, if he tries to obtain it by means of purely nitrogenous manures when his soil is already unduly exhausted of mineral constituents.

The above table is taken from a more comprehensive one, which also gives the result on each plot for every one of the 12 years. As showing the difference of effect of a given amount of ammonia in one season as compared with another, the results on plot 6, receiving 50lb. of ammonia (in 200lb. of ammonia-salts) each year, and always with mixed mineral manure, are instructive. Taking the average of the 12 years, it required 4·86lb. of ammonia in manure to yield 60lb. of increase of grain and its proportion of straw; whereas, in the remarkably productive season of 1863, it required only 2·42lb., but in 1853, 7·13lb.; in 1860, 8·85lb.; and in 1852, 12·45lb.

The conclusion on the point under notice is that, great as is the difference of effect of a given quantity of ammonia, according to the amount applied per acre, to the mineral condition of the soil, and to the season, still, when only moderate quantities were used, when there was a sufficient supply of mineral constituents, and taking the average of many seasons —that is, under the conditions the most comparable with those of the average of common practice,—the result was in marked accordance with the early estimate, that almost exactly 5lb. of ammonia were required to be expended to obtain an increase of one bushel of wheat grain and its proportion of straw.

THE ROTHAMSTED EXPERIMENTS ON THE CONTINUOUS GROWTH OF WHEAT COMPARED WITH THOSE AT WOBURN, HOLKHAM, AND RODMERSHAM.

It may fairly be objected that these experiments on the continuous growth of wheat furnish results true of one description of soil and of one locality only. Table XII., however, summarises the results of experiments made on very various soils, under various conditions due to previous treatment, and in various seasons, notwithstanding which the general characters of the results are seen to be accordant.

TABLE XII.—RESULTS OF EXPERIMENTS ON THE GROWTH OF WHEAT BY DIFFERENT MANURES, ON DIFFERENT SOILS, IN DIFFERENT LOCALITIES, AND IN DIFFERENT SEASONS.

Manures.	Dressed grain per acre—bushels. Average annual results.					
	Rothamsted, Herts.			Woburn, Beds.	Holkham, Norfolk.	Rodmersham, Kent.
	8 years, 1856-63.		32 years, 1852-83.	7 years, 1877-83.	3 years, 1852-54.	4 years, 1856-59.
	Broadbalk Field.	Hoos Field.	Broadbalk Field.			
Unmanured	16	15	$13\frac{1}{8}$	$15\frac{7}{8}$	18	$25\frac{5}{8}$
Mix. min. man. alone ...	19	$16\frac{1}{8}$	$15\frac{1}{4}$	$16\frac{7}{8}$	$19\frac{1}{8}$	$28\frac{1}{2}$
Amm.-salts alone (86lb. nitrogen)	$23\frac{1}{4}$	$26\frac{1}{8}$	$20\frac{7}{8}$	$23\frac{5}{8}$*	$27\frac{1}{4}$	$31\frac{1}{2}$
Mix. min. man. and amm. salts (86lb. nitrogen).	$38\frac{1}{2}$	$37\frac{3}{8}$	$32\frac{3}{4}$	$37\frac{5}{8}$	$32\frac{5}{8}$	$33\frac{1}{2}$

* By amm.-salts = only 43lb. of nitrogen.

Thus, not only is there general agreement in the character of the results in different localities, when the averages of a number of years are taken, but the non-effect of the residue from previous applications of ammonia-salts is as marked in the sandy soil at Woburn as in the very different loamy soil at Rothamsted. This latter point is illustrated in Table XIII., which shows the produce of wheat grown year after year on the same land in Stackyard Field, Woburn.

This field received mineral manure and ammonia-salts (= 86lb. of nitrogen) for five successive years, in the year following which one portion again received the same manure, and the other the mixed mineral manure alone. In the next year, 1883, the portion which received the whole manure in the previous year received mineral manure only; whilst the other portion received both minerals and ammonia-salts. It is seen that in each year, 1882 and 1883, the nitrogenous-manured portion yielded large crops ($43\frac{1}{2}$ and $45\frac{3}{4}$ bushels); whereas, the portion on which mineral manures alone followed ammonia-salts and large crops, yielded very small

TABLE XIII.—WHEAT GROWN YEAR AFTER YEAR ON THE SAME LAND, STACKYARD FIELD, WOBURN.

Harvests.	Dressed grain, bushels.	
1877	$43\frac{3}{8}$	
1878	27	
1879	$31\frac{1}{4}$	
1880	$28\frac{3}{8}$	
1881	$43\frac{5}{8}$	
1882	(1) $13\frac{1}{4}$	(2) $43\frac{1}{2}$
1883	(2) $45\frac{3}{4}$	(1) $17\frac{1}{4}$

(1) Mixed min. man. alone. (2) Mixed min. man. and amm.-salts. (= 86lb. nitrogen.)

crops—$13\frac{1}{4}$ and $17\frac{1}{4}$ bushels respectively, against $14\frac{7}{8}$ and $17\frac{1}{4}$ bushels on a plot where the same mineral manures were used year after year. There was, then, no available and effective residue where the ammonia-salts had been previously applied. Though in 1884 there was notable effect from unexhausted residue of nitrogenous manure, this probably arose from there being very little rain, and, consequently, very little loss by drainage during the winter of 1883-4.

SUMMARY OF THE RESULTS OF FORTY YEARS' EXPERIMENTS ON THE CONTINUOUS GROWTH OF WHEAT UPON THE SAME LAND.

The forty years' experiments on the continuous growth of wheat have established, with regard to the soil, the following facts. An unmanured soil has yielded forty successive crops, averaging 14 bushels per acre, solely by means of its existing fertility. At the outset the soil contained a large amount of organic nitrogen, derived from previous vegetation; it likewise contained a large amount of mineral food. Every year a portion of the organic nitrogen has been nitrified by the agency of organisms living in the soil; part of the resulting nitrates has contributed to the growth of the wheat crop, and part has been washed out of the soil or otherwise lost. This loss of nitric acid is greater in wet seasons, and the amount taken up by the wheat crop is consequently smaller; so that comparatively dry seasons should be favourable to the production of large wheat crops. The stock of soil fertility in the form of organic nitrogen has been considerably reduced, and the stock of both potash and phosphoric acid has likewise been largely reduced. Nevertheless, the stock of fertility that remains would appear to be sufficient to grow crops of wheat for a very long period, though the produce must necessarily lessen in course of time.

With regard to manures, minerals alone have added very slightly to the unmanured produce, whereas manures containing nitric acid alone, or some easily nitrifiable compound of nitrogen, have considerably increased the crop; hence the soil had a stock of minerals which the crop was unable to utilise, on account of the insufficient supply of available nitrogen. Manures consisting of potash, phosphoric acid, and nitrogen (as ammonia-salts, or as nitrates), appear competent to grow large crops of wheat continuously. In the ordinary course of agriculture with rotation, as practised in this country, the supply of mineral constituents immediately available for the wheat crop is almost invariably in excess, relatively, to the immediately available supply of nitrogen from the atmosphere, or the accumulated stores within the soil itself. Furthermore, with few exceptions, the worse the so-called "condition" of the land—that is, the more it is in the agricultural sense exhausted—the more striking would be the effect of exclusively nitrogenous as compared with that of exclusively mineral manures. A given weight of nitrogen, as nitric acid (or nitrate), has produced more growth than the same weight of nitrogen as ammonia-salts. The amount of nitrogen supplied in the manures is very much in excess of the amount recovered in the increase of the crops; and, after a certain amount of growth has been reached, each increase of crop requires a proportionately larger application of manure. When the price of wheat is high, larger crops can be grown more profitably than when the price is low. In the form of farmyard manure, a considerably larger amount of nitrogen is necessary to produce a given increase of crop; but, though a given weight of nitrogen, in the form of nitric acid, will produce more growth than the same weight of nitrogen in dung, the influence of the nitrate upon succeeding crops will be very much less. There is no evidence to show whether the whole available effect of the nitrogen in one manure is greater than it is in the other.

Finally, with regard to unexhausted manures, it appears that, in the absence of vegetation, or when applied to crops in excess of their requirements, both potash and phosphoric acid form insoluble compounds with the soil, and become available for future crops. Under similar circumstances, nitrates and salts of ammonia do not appear to form permanent compounds with the soil, but are liable to be washed out by rain, or to be otherwise lost. The application of more nitrogen, as nitrates or salts of ammonia, than the crop can utilise, does not appear to interfere with the nitrification of the organic nitrogen of the soil. The stock of nitrogen of the soil itself, therefore, may be reduced, although the annual application of nitrogen may be much in excess of the amount of that substance removed in the crop. When large wheat crops have been grown by the use of nitrates or salts of ammonia, with mineral manures, the soil does not appear to have gained or lost fertility. Nitrification may have gone on as usual, but the loss has been made good by the amount of nitrogen stored up in the stubble and underground portions of the large crops so grown. When dung is applied continuously, the accumulation of unexhausted fertility becomes very large, and the removal by crops of the substance accumulated would extend over a long series of years; therefore, dung applied to land in the ordinary process of agriculture will not be entirely exhausted until a considerable number of years from the time of its application.

IV.—INFLUENCE OF CLIMATE ON THE CULTIVATION OF WHEAT.

"Our Climate and Our Wheat Crops" is a title so suggestive of important agricultural and economic problems, that it is hardly surprising it should have been made the subject of an essay (R. A. S. Journal, 1880), in which Messrs. Lawes and Gilbert sought to trace a connection between the general character of the seasons and the amount of their respective wheat crops. It has been remarked that, so far as climate is concerned, the British Isles are outside the zone favourable to the growth of wheat, and that its successful cultivation is due to the skill of the farmer in contending against adverse meteorological conditions; that, however, the decline in the wheat area cannot be attributed to any general change for the worse in the characters of the British climate, is proved by the circumstance that, by dividing the 108 years ending with 1880, into six periods of eighteen years each, there is even a slight progressive increase of mean temperature from the first to the last of these six periods (Mr. Glaisher). It is to the greatly increased production of wheat in other countries at a lower cost than in our own, and to low rates of transport, by which it is brought into our markets in quantity and at a price much reducing the value of home produce, that the lessened area under the crop is chiefly to be attributed.

As only about 5 per cent. of the total wheat crop is derived from the soil itself, the remainder coming, directly or indirectly, from the atmosphere; and as the amount of matter accumulated from either source depends mainly on the quantity, and the relations to one another, of heat and moisture, the preponderating influence which the character of the seasons exercises over the growth of our crops is no more than might be expected. Though the connection between meteorological phenomena and the progress of vegetation is not yet so clearly comprehended as to enable us to estimate with any accuracy the yield of a crop by studying the statistics of the weather during the period of its growth, the present attempt is, nevertheless, a valuable contribution towards such an object.

Temperature and rainfall are the chief factors demanding attention, but it is necessary to distinguish between the total heat and the total rainfall of a season, and the distribution of temperature and of rainfall over the different periods of the season. It is obvious that a given amount of rain equally distributed through the spring and summer in each of two seasons, will have a very widely different effect on vegetation in the two cases, if the one season should be a hot and the other a cold one. On the other hand, if the temperature of the two seasons be the same, but the rainfall very different, so also will the effect on vegetation be very different. The defect of our climate for the production of wheat is apparently more connected with an excess of moisture than with a deficiency of heat, during the periods of active growth and maturing. It is, in fact, when a cold season, or one of only moderate temperature, is accompanied by an excess of rain, that the yield of our wheat crops is the most defective.

During the present century, each of the following years was more or less remarkable so far as the growth of the wheat crop is concerned; 1816, 1832, 1833, 1834, 1835, 1853, 1854, 1857, 1860, 1863, 1864, 1868, 1870, and 1879. Of these, 1816 and 1879 have the reputation of yielding the two worst wheat crops within the period included by those dates; on the other hand, 1834 is generally referred to as one of the most productive years of the century. Four seasons of reputed very high productiveness which occurred before the commencement of the Rothamsted experiments, were those of 1832-3-4-5. So abundant were these four wheat crops, that the average price, even under protection, went down from 54*s.* 5*d.* per quarter over the first harvest year, to 49*s.* 9*d.* over the second, 41*s.* 5*d.* over the third, and 42*s.* 8*d.* over the fourth. The lowest price reached was 36*s.* per quarter in the last week of 1835, and the first of 1836. And such was the distress suffered by the agricultural interest, as the result of abundant wheat crops, and the low prices following, that select committees of both Houses of Parliament were appointed to inquire into the matter; in 1880 a Royal Commission inquired into the distress caused, not by abundant, but by deficient crops and large importations, though by no means such low prices as during the period of great abundance. The characters of some of the remarkable seasons may now be noticed.

The abundant wheat crop of 1832 was grown under the influence of a mild and rather wet winter, a spring of moderate characters, and a summer of only moderate temperatures, and with heavy rains excepting in July. The crop of 1833 was the result of a generally mild and moderately wet winter and early spring, excepting January and March, which were cold. The remainder of the spring and the early summer were hot and mostly dry, and the rest of the season upon the whole favourable. The result was a high yielding, but not bulky, straw crop. The crop of wheat of 1834—one of the heaviest on record—was grown in a season warmer than usual almost throughout, but especially in the winter and in the spring, excepting April; and, after an excess of rain in the winter, there was a considerable deficiency for four months to the end of May, again a deficiency in June, but afterwards heavy rains, though with high temperatures. The crop of 1835, which was of extraordinary bulk and luxuriance, was grown in a season in which the winter was as open and as much marked by an absence of snow and frost as the three preceding winters; the spring was, upon the whole, favourable to the wheat crops, and the summer brilliantly fine till the last week in June. At the end of June heavy rains and high winds laid the crops; but bright breezy weather in July stayed the damage, though much did not ripen well. The rest of the season was fine, and the wheat crops were got in in excellent order; but, though bulky, they were decidedly inferior in both yield and quality to those of 1834. Generally, then, these four consecutive seasons of abundant wheat crops were characterised by mild and open winters, upon the whole mild springs, and average, or warmer than average, summers, especially the last two of the four. In each season there were individual months of considerably more than average fall of rain, sometimes earlier and sometimes later, and accordingly influencing the bulk of the crop. But each season was characterised by less than the average fall of rain during several months of the growing period, and this was particularly the case in the season of 1834, the one of the most extraordinary productiveness.

Passing now to those seasons of high productiveness which have occurred during the progress of the Rothamsted experiments, the season of 1854 comes first in chronological order. The crop, which was very abundant both in corn and straw, was, after a severe winter period, grown under higher than average temperatures during the earlier, but lower during the later, periods of growth, and with much less than the average fall of rain in every month from seed-time to harvest, excepting in May and August. The heavy corn, but not heavy straw, crop of 1857 was obtained under the influence of about average winter and early spring, but high summer, temperatures, and, as in other cases of high productiveness, there was here again much less than the average fall of rain from seed-time to harvest, the only months of any excess being January, June, and August. The wheat crop of 1863 gave probably the highest average produce per acre over the country at large since 1834; its season of growth was marked by an extremely mild winter and early spring, with much less than the average fall of rain, so that the plant was brought early forward. Then came, in the early summer, a considerable amount of rain, after which there was a deficiency up to harvest. The temperature was only about the average in June and July, conducing to continued luxuriance rather than to early maturation; whilst August, the harvest month, was both warmer and drier than usual. The conditions were, therefore, those of a lengthened and almost unbroken course of gradual accumulation, with, finally, a favourable ripening period. The crop of 1864 was produced under the influence of warmer than average weather in early winter and in spring; only moderate, or even lower than average summer, temperatures, but much less than the average fall of rain from seed-time to harvest; every month being considerably deficient, excepting May, which was average, and March, in which alone there was an excess. In the season of 1863 the period of growth was almost throughout one of drought, with high temperatures prevailing through spring and summer; the result was a very early harvest, a not bulky but a high-yielding crop on good and well-farmed soils, but a deficient one on light and poorly-farmed land. After a by no means favourable winter, followed by prolonged spring and summer drought and heat, the wheat crop of 1870 was deficient in straw, and also yielded less corn than that of 1868, but still considerably more than the average, with a high proportion of corn to straw, and high quality of grain. Generally speaking, out of the six years of highest productiveness throughout thirty-six seasons (1844-1879) of experiments, the three which gave the highest produce of all (1863, 1864, and 1854) were marked by generally higher than average mean temperatures during the winter and early spring (excepting the early winter of 1853-4, which was severe), but generally only average, or lower than average, summer temperatures. Indeed, June, 1854, was colder than June of the disastrous year 1879. Each was also characterised by very much less than the average fall of rain from seed-time to harvest, there being in no case an excess in more than two out of the nine months from November to July inclusive. The other three seasons of high productiveness (1857, 1868, and 1870), though they gave less corn than the foregoing, and very much less straw, were, nevertheless, seasons of considerably more than average produce of corn, and of high quality of grain. These crops were grown under much more variable winter conditions as to temperature, but under much higher both spring and summer temperatures, especially those of 1868 and 1870; whilst, with the higher temperature there was, as in the cases with lower temperature and more abundant crops, much less than the average fall of rain from seed-time to harvest, one or two months only showing an excess.

Turning to the seasons of unusually low productiveness, in that of 1853 the early winter had been unseasonably wet and warm, the land being generally saturated with water, and in many cases flooded; the spring was unseasonably cold, and also wet, and the summer was, upon the whole, colder than the average, and very wet. The characteristics of the season of 1860, yielding a crop both late and much below the average both in quantity and quality, were a winter alternately very cold and very mild, and upon the whole wet, followed by a spring, summer, and autumn generally stormy, cold, wet, sunless, and unseasonable. In the season of 1879 there was, from seed-time to harvest, a considerable deficiency of temperature, compared with the average, in every month excepting March. It is remarkable, however, that there was even a lower mean temperature in June, 1854—a season of very great abundance—than in June, 1879, the season of the worst crop known within the century. But it was by the continuity and excessive amount of the rainfall that the season of 1878-9 was especially characterised, the excess during the eleven months, from November to September inclusive, being more than eleven inches over the average, and the total amount was more than double that over the same period of some of the seasons of high productiveness. A comparison of 1879 with 1816 shows that the former year was characterised by a season which was, from seed-time to the end of the summer, worse than that of the latter. 1816 suffered more from low temperature, but less from excess of rain during the summer. Both crops were, however, very late, and, for getting in the crop, the season of 1816 was much worse than that of 1879.

It is now desirable, disregarding as much as possible the specialities of individual seasons, to consider the average character of classes of seasons, arranged according to the general character of their wheat crops. The classes are as follows: Six years of high produce of both corn and straw—1832, 1834, 1835, 1854, 1863, and 1864; four years of high produce of grain, but not of straw—1833, 1857, 1868, and 1870; four years of very low produce—1816, 1853, 1860, and 1879.

Taking the six years of high produce, and confining attention, in the first place, to the period of six months, from November to April inclusive, in only one of the six seasons which go to make the average were there two months, and in four others there was only one month, of the six of in any material degree lower than average temperature, and in only one season (1854) was there a really severe winter month. With these few exceptions, every other month of the six within each of the six seasons was either about average or over average, and in many cases very much over average, as to temperature. As to rainfall over the same period, in two of the seasons there were two months, and in two there was only one month with any considerable excess of rain; whilst in the other two there was a deficiency in every month of the six. There were, therefore, in each of the six seasons, four, five, or six of these six months considerably drier than the average. Concerning the next three months of May, June, and July: in two out of the six seasons, each of the three was warmer than the average, in two each was colder than the average, and in two there were warmer and colder months, with about average mean temperatures. As to rainfall, in one out of the six years there were two of the three months, in four there was only one of the three, and in the other there was no month, with an excess of rain. In only one of the six years was the total rain of the three months over the average; though in three of the six seasons there was an excess in August. It may be added that the average mean temperature of these six seasons was higher than that of one hundred and eight years (1771-1878) in every month of the twelve; but the excess was very much greater in the months prior to May, than in May and afterwards. Upon the whole, then, these seasons of highest productiveness were characterised by higher than average temperatures during most of the winter and the early spring. Some were considerably warmer during the summer also, but the majority were characterised by but little higher, or even lower, than average temperatures in the summer. There was also a prevailing deficiency of rain in the winter and spring, but a less marked deficiency in the summer.

In the second class of seasons, those of high produce of grain, but of small produce of straw, and therefore of comparatively small total produce, the distribution of the excess of temperature is exactly the opposite of that observed in the case of the seasons of heaviest gross produce. The result was associated with little more than fairly average conditions as to temperature during the early stages of development of the plant, but with a considerable excess during the period of active above-ground growth, and of maturation. There is, at the same time, though a considerable total deficiency of rain, a much more marked deficiency during the periods of more active above-ground growth, and of ripening, than during the earlier stages.

In the third class of seasons, those of unusually low produce, the averages show an actual deficiency of temperature in ten months out of the twelve; and in only one from seed-time to harvest was there an average excess of any importance, namely, in January. With this great deficiency of average temperature, there appears, almost throughout, an excess of rain, the excess being very much the greater in April, and afterwards up to harvest, than previously. The number of rainy days is also greatly in excess, especially in the summer months. Very low productiveness was, then, associated with both low temperatures and excess of rain, especially during the periods of more active above-ground growth and ripening.

In Table XIV. the column A refers to the six seasons of much both grain and straw; the column B to the four seasons of much grain but not much straw; the column C to the four seasons of low produce. The averages are made up from different periods, as noted at the foot of the table, and all the figures are deduced from the records at Greenwich. The wheat season is, of course, from October to September.

TABLE XIV.—SUMMARY OF TEMPERATURE AND OF RAINFALL.

	A.	B.	C.	Average.*
Average monthly mean temperature (degrees F.)	49·7	49·8	47·2	48·6
Annual rainfall (inches)	21·44	19·53	32·89	25·4
Number of days on which 0·01in. rain, or more, fell	140	136	199	141

* In the first line the average temperature is that of 108 years—1771-1878. In the second line the average rainfall is that of 63 years—1815-1877. In the third line the average number of days is that of 55 years—1815-1869.

From the comparisons which have now been made of the various seasons, it would appear that mildness and comparative dryness, of at any rate considerable portions of the winter and early spring, favouring root development, that is, an extended possession of the soil by the plant, and a somewhat early start, have been the characteristics of the most productive seasons. Indeed, with these favourable early conditions, an abundant and high-yielding crop may be obtained with only fairly average or even under average summer conditions. But there can be little doubt that, when high summer temperatures, without excess of rain, do succeed upon the favourable conditions of early growth and of plant just mentioned, the proportion of grain yielded by the bulky crop will be the greater. The less bulky, and somewhat less abundant in grain, but still high-yielding crops have, on the other hand, generally had less favourable conditions for winter root development, and for early growth in spring, but have been developed under the influence of considerably higher than average summer temperature, with, at the same time, deficiency of rain almost throughout, and a considerable deficiency during the summer months.

The seasons of unusually deficient wheat crops have been characterised by severe, or at any rate very changeable, winter and spring conditions, with, at the same time, generally an excess of rain during these periods, frequently saturating the soil, causing much drainage, and discouraging root development and early growth in spring. But the more striking characteristic of the bad seasons is a great deficiency of average temperature, and especially a great excess of rain, from the period of active above-ground growth until harvest. The crop of 1816, however, suffered more from low temperature than from excess of rain, and that of 1879 much more from an excess of rain than from low temperature until mid-autumn, after which 1816 continued wet, and 1879 became dry. It would appear that any defect of our climate in appropriateness for the production of full and well-matured wheat crops is more connected with an excess of rain, and consequent wetness of soil and humidity of atmosphere, than with any deficiency of average summer temperature.

A few more words, in conclusion, respecting the never-to-be-forgotten season of 1879. In that year the wheat plant, which luxuriates in a comparatively dry soil and climate, passed its whole existence under exactly opposite conditions, and the result was only what might have been expected.

Though it has long been known that an excess of rain is injurious to the wheat crop, it is only within comparatively recent years that one, at least, of the material causes of the adverse influence has been clearly made out, namely, the great loss of nitrogen carried off by drainage in the form of nitrates. Moreover, when the manures are autumn-sown, this loss is much greater during the winter than during the later period of the season. Table XV. shows the bushels of grain and the weight of straw, and of total produce, obtained in each of the seven years, from 1873 to 1879 inclusive, by autumn sowing and by spring sowing respectively, of the ammonia-salts.

TABLE XV.—AUTUMN SOWING AND SPRING SOWING OF AMMONIA-SALTS.

Seasons.	Dates of sowing ammonia-salts.		Grain, Straw, and Total Produce per acre.					
			Grain.		Straw.		Total Produce.	
	Autumn.	Spring.	Autumn sown.	Spring sown,	Autumn sown.	Spring sown.	Autumn sown.	Spring sown.
			Bushels.	Bushels.	lb.	lb.	lb.	lb.
1873	Oct. 18	Mar. 25	22	32⅝	2021	3079	3344	5031
1874	" 28	" 19	39⅜	29⅛	4645	2776	7094	4588
1875	" 23	" 23	25⅞	25½	3422	3204	5110	4915
1876	" 30	" 24	23½	25½	2212	2428	3793	4083
1877	" 17	Apr. 11	19⅞	33⅛	1835	2788	3048	4795
1878	Nov. 3	Mar. 14	22⅛	31¼	3071	4952	4486	7017
1879	Oct. 15	" 10	5⅜	16¼	906	3012	1275	4063
Averages			22½	27¾	2587	3177	4021	4927

Only in 1874, therefore, was the result decidedly in favour of autumn sowing. In 1873, 1877, 1878, and 1879 it was decidedly against autumn sowing; whilst in 1875 and 1876 the difference was immaterial. It is particularly worthy of note that during the period between the autumn sowing and the spring sowing the rainfall was far less in the season of 1874 than in any of the others. The season of 1875 ranks next in this respect.

Hence, independently of other adverse effects arising from low temperature and excess of rain, the Rothamsted experimental wheat crops of 1879 suffered very considerably from loss of the nitrogen of the manure by drainage. Experimental evidence proves that similar loss may arise when animal nitrogenous manures (such as hair, horn shavings, woollen rags, &c.) and vegetable nitrogenous manures (such as rape-cake) are used. Further, the drainage water from the dunged plot in the experimental wheat-field is sometimes found to contain a considerable amount of nitric acid, but always very much less than that collected at the same time from adjoining plots receiving much less nitrogen as manure, but in the form of ammonia-salts or nitrate of soda. Whilst, therefore, it is to be assumed that the loss of the nitrogen of manure by drainage in the season of 1879 was proportionally much greater in the experimental wheat-field than in the case of land farmed in the ordinary way, there can nevertheless be no doubt that much of the land of the country at large also suffered loss in the same way.

V.—THE HOME PRODUCE, IMPORTS, AND CONSUMPTION OF WHEAT.

Inasmuch as wheat furnishes the staple food of the British people, all questions affecting this cereal are necessarily of profound economic interest. Messrs. Lawes and Gilbert have written two papers "On the Home Produce, Imports, and Consumption of Wheat" (R.A.S. Journal, 1868, and 1880, and also Journal of the Statistical Society, June, 1880); and at the outset of the inquiry, they had to face very serious difficulties arising out of the crude and imperfect character of the statistical information at their disposal, though since then some improvement has been effected in the official collection of agricultural statistics. The second of the two papers now under notice does not extend beyond the season of 1879-80, nevertheless, in the tables which follow, the statistical record is brought down to the harvest of 1887.

In a paper on "Our Daily Food; its Price and Sources of Supply," read before the Statistical Society, March 17, 1868, Mr. (now Sir) James Caird estimated the cost of wheat and wheat flour consumed in the United Kingdom at 30,000,000*l.* sterling more for the year, in consequence of the bad season of 1867, than after the good harvest of 1863, and that out of this total extra cost, 27,400,000*l.* more would have to be paid for foreign corn after the bad harvest than after the good one. He noticed the influence which such a result must have upon the trade of the country, and insisted upon the great advantages which would accrue from early knowledge as to the area and yield of our various crops. During only the preceding two years (1866-7) had voluntary returns been collected throughout the United Kingdom referring to the number of acres under each crop, and to some other points; but, in regard to the important question of the amount of produce obtained, either per acre or in the aggregate, there were no returns nor any reliable information. In these circumstances certain of the plots of the experimental wheat-field at Rothamsted were, after careful observation and comparison, selected as affording a trustworthy estimate of the general yield over the country, and every year since 1862 there has appeared in the *Times* a letter containing an estimate of the yield of wheat for the current season. The results of the experimental wheat-field were regarded by Mr. Caird, in the above-mentioned paper, as having "proved a very satisfactory index of the general yield over the chief wheat-producing area of the kingdom," and as affording "the most instructive series of facts for the guidance of the British corn-grower on record." The selected plots comprise:

Plot 3.—Unmanured every year, experiment commencing 1843-4.

Plot 2.—14 tons farmyard manure every year, commencing 1843-4.

Plot 7.—Mixed mineral manure, and 400lb. ammonia-salts, each year, 1851-2 and since.

Plot 8.—Mixed mineral manure, and 600lb. ammonia-salts, each year, 1851-2 and since.

Plot 9.—Mixed mineral manure, and 550lb. nitrate of soda, each year, 1854-5 and since.

In forming the estimate of the average produce per acre of the country at large, the plan adopted is to take the mean produce of the unmanured plot, of the farmyard manure plot, and of the three artifically manured plots reckoned as one, and to reduce the result so obtained to bushels of the standard weight of 61lb. per bushel. Merely as an example, Table XVI., published in October, 1787, is given. Though experience proves that this mode of estimates leave but little to be desired as a means of computation of the average yield of the country over a number of years, it has not been found

TABLE XVI.—ESTIMATED YIELD OF WHEAT PER ACRE, 1887.

Bushels of Dressed Grain per Acre.

Harvest.	Unmanured. Plot 3.	Farmyard manure. Plot 2.	Artificial manures.			Mean of Plots 7, 8, and 9 (or 16).	Means of Plots 3, 2, and 7, 8, 9 (or 16).
			Plot 7.	Plot 8.	Plot 9 (or 16).		
Present year, 1887	14⅞	34¾	29½	34½	39⅝	34½	28 (1)
Average 10 years, 1877-86	11¼	31⅜	30½	35	36¾	34	25½ (2)
Average 25 years, 1852-76	13¾	34¾	33⅞	37⅛	36⅝	35⅞	28⅛ (3)
Average 35 years, 1852-86	13	33¾	32⅞	36½	36¾	35⅜	27⅜ (4)

Weight per Bushel of Dressed Grain, in lbs.

Harvest.	Unmanured. Plot 3.	Farmyard manure. Plot 2.	Artificial manures.			Mean of Plots 7, 8, and 9 (or 16).	Means of Plots 3, 2, and 7, 8, 9 (or 16).
			Plot 7.	Plot 8.	Plot 9 (or 16).		
Present year, 1887	59¾	62¾	62	63⅛	63	62¾	61¾
Average 10 years, 1877-86	58¾	60½	60⅜	60⅜	59½	60⅛	59¾
Average 25 years, 1852-76	57¾	60⅛	59⅜	59⅛	58⅝	59	59
Average 35 years, 1852-86	58⅛	60¼	59⅝	59½	58⅞	59⅜	59¼

Total Straw, Chaff, &c., per Acre, cwt.

Harvest.	Unmanured. Plot 3.	Farmyard manure. Plot 2.	Artificial manures.			Mean of Plots 7, 8, and 9 (or 16).	Means of Plots 3, 2, and 7, 8, 9 (or 16).
			Plot 7.	Plot 8.	Plot 9 (or 16).		
Present year, 1887	8	30⅞	24⅛	32¼	36¼	30⅞	23¼
Average 10 years, 1877-86	8⅝	28¼	32	40¼	42¼	38⅛	25
Average 25 years, 1852-76	12	33	34	40⅝	41¾	38¾	27⅞
Average 35 years, 1852-86	11	31⅝	33½	40½	41⅞	38⅝	27⅛

(1) Equal to 28⅜ bushels, at 61lb. per bushel.
(2) Eqnal to 25 bushels, at 61lb. per bushel.
(3) Equal to 27¼ bushels, at 61lb. per bushel.
(4) Equal to 26⅝ bushels, at 61lb. per bushel.

to be equally applicable for each individual year. The so-calculated average produce per acre on the selected plots gives somewhat too high a result for the country at large in seasons of great abundance, and too low a result in unfavourable seasons. Accordingly, in some seasons, instead of the actual average indicated by the experimental plots, a higher or a lower figure has been adopted; and especially in the case of some of the then (1880) recent bad seasons a higher one was taken.

Independently of any such admitted differences between the so directly calculated and the actually adopted estimates for individual years, the question arises—Whether the average result indicated by the several selected plots remains as applicable as heretofore; or whether the produce of some is annually declining, or that of others annually increasing, irrespectively of the influence of season, so as to vitiate the continued applicability of such results for the purposes of such an estimate? This point has already been discussed in connection with the forty years' experiments on the continuous growth of wheat, so that it is only necessary here to repeat that the produce of the unmanured plot is gradually declining from exhaustion, that the farmyard manure plot is increasing in fertility, and that there is no evidence of material increase or material decrease on either of the plots receiving ammonia-salts other than that due to season. Comparing the direct average of the experimental plots with that actually adopted as the average for the United Kingdom each year, the experimental plots indicate for the whole twenty-eight years (*i.e.*, up to 1879-80) about three-quarters of a bushel less per acre per annum than the actually adopted estimates founded upon them.

Taking the average of the twenty-eight years' adopted estimate of produce per acre as 100, the first column of Table XVII. shows the deviation from this general average for the whole period, over the first eight, the second eight, the third eight, and the last four years of the twenty-eight; and the second column shows the deviation, from the same standard, of the average produce per acre on the selected plots.

After making allowance for the seasonal variations in each of these periods, it appears that, in fairly average seasons, the mean produce of the experimental plots fairly represents the average produce; that in seasons of unusual abundance the experimental plots indicate too high a figure, and that in seasons of great deficiency they give too low a figure. Still, it is, upon the whole, concluded that there is no better basis for estimating the annual yield of the country each year than that of the average produce of the same selected plots as heretofore relied upon; but that, as heretofore, some judgment must be exercised each year, according to the characters of the season, in deciding whether to adopt the actual figure indicated by the experimental plots, or in which direction, and in what degree, it should be modified.

TABLE XVII.—SHOWING THE DEVIATION OVER EACH SEPARATE PERIOD FROM THE ADOPTED AVERAGE OF THE WHOLE PERIOD TAKEN AS 100.

	Actually adopted averages.	Averages of Plots 3, 2, and 7, 8. and 9.
First eight years, 1852-59 ...	103	101
Second eight years, 1860-67...	104	106
Third eight years, 1868-75 ...	98	99
Last four years, 1876-79	89	71
Total period, 28 years ...	100	98

In illustration of the difficulty of this inquiry, it will be appropriate to notice at this stage the nature of the data upon which the investigators had to rely for information upon the following points: 1. The area under wheat. 2. The average yield of wheat per acre. 3. The aggregate home produce, and the amount of it available for consumption. 4. The imports. 5. The population. 6. The average consumption of wheat per head of the population per annum.

1. From 1852 to 1865 inclusive, it was necessary to rely on estimates alone in fixing the area under wheat in England

and Wales. For Scotland, there were the returns collected by the Highland Society for 1854, 1855, 1856, and 1857; but for the two years prior to 1854, and for the years subsequent to 1857, down to 1865 inclusive, estimates only were available. For Ireland, returns were available throughout. From 1866 onwards the "Agricultural Returns" have given the much-needed official information as to the acreage of wheat in the United Kingdom.

2. The only returns or official estimates as to the average yield of wheat per acre were for Scotland for four years, and for Ireland for each year within the period of the inquiry. For England and Wales, comprising from 85 to 90 per cent. of the total area under wheat, it was necessary, in the absence of any official information whatever, to fall back upon the average produce per acre each year of the selected plots at Rothamsted, in the manner already described.

3. The aggregate home produce is deduced from a knowledge of the acreage under crop, combined with a trustworthy estimate of the average yield per acre, whilst the amount available for consumption is arrived at by deducting from the total produce the quantity annually returned to the land as seed. On adequate grounds it is assumed that $2\frac{1}{4}$ bushels per acre are required for this latter purpose.

4. The imports have throughout been taken from the Returns for the United Kingdom, either of the net imports of wheat and wheat flour, or of the imports and exports from which the net imports can be calculated. Moreover, the net imports have been calculated, not for the calendar years, but for the harvest years, that is, from September 1 of one year to August 31 of the next.

5. The figures as to population are taken from the estimates of the Registrar-General. The middle of the calendar year being the end of June, and the middle of the harvest year the end of February, the plan adopted has been to add to the number officially recorded for the preceding midsummer two-thirds of the difference between that figure

and the number given for the next midsummer, thus bringing the estimate up to the end of February. Any irregularities are detected immediately after the Census years.

6. The average consumption of wheat per head of the population per annum is a difficult matter to determine. In the first paper (1868) the estimate was founded on the calculation of eighty-six different dietaries, arranged in fifteen divisions, according to sex, age, activity of mode of life, and other circumstances; and the result so obtained was compared with that arrived at on the basis of the population, and of the amounts of the available home produce, and of the net imports of wheat each year. For Scotland, and for Ireland, it was only possible to found an estimate on the basis of population, and on the amounts of the home and foreign supplies. On these bases the average consumption of wheat in the United Kingdom collectively was estimated to be $5\frac{1}{2}$ bushels per head of the population per annum, during the later years to which the inquiry related. This estimate is, in the course of the second paper (1880), submitted by the investigators to close criticism. They comment on the fact that the average consumption per head has increased in the United Kingdom as a whole since the establishment of free trade in corn, though probably more rapidly at first. The quantity consumed will vary according to the prosperity or otherwise of the people, to the price of wheat itself, and to that of other articles of food also. Independently of the influence of lower prices for wheat, and of the increased prosperity of the masses of the population, among the circumstances tending to increase the consumption of wheat in recent years may be mentioned the increased price of meat; whilst, among those tending to limit the rate of increase of consumption, may be noted the fact that the proportion of the total wheat consumed which is derived from foreign sources is rapidly increasing, and the drier foreign wheats will undoubtedly yield a larger percentage of flour, and flour

of better quality than much of the home-grown grain. Upon the whole, the investigators were led to conclude that their estimates of consumption (5·1 bushels per head per annum) over the first period of eight years (1852-59) might be somewhat too low; also that their previously published estimates of consumption for the years subsequent to the first sixteen, were more probably too low than that their estimates of average produce per acre, and of aggregate produce founded upon them, were too high. For reasons assigned, however, they adopt in their second paper their previous estimates of average produce per acre each year without

TABLE XVIII.—YIELD OF WHEAT PER ACRE PER ANNUM.

	Average produce per acre.	
	According to increased consumption and imports.	According to annually adopted estimates.
	Bushels.	Bushels.
Average 8 years, 1852-3—1859-60...	$28\frac{1}{8}$	28
Ditto 1860-1—1867-8 ...	$28\frac{3}{8}$	$28\frac{3}{8}$
Ditto 1868-9—1875-6 ...	$26\frac{1}{2}$	$26\frac{3}{4}$
Average 3 years, 1876-7—1878-9 ...	27	$27\frac{1}{4}$
Average 27 years, 1852-3—187	$27\frac{5}{8}$	$27\frac{5}{8}$

change. They also adopt their previous estimates of consumption per head for the first two periods of eight years each without change—5·1 bushels and 5·5 bushels respectively. But, for the third period of eight years, they assume the consumption to be at the rate of 5·6 bushels per head, and for the last three years (1876-78) at the rate of 5·65 bushels, instead of 5.5 bushels over those eleven years, as previously reckoned; and, until further experience should indicate further change to be necessary, they propose to adopt $5\frac{2}{3}$ bushels as the average consumption per head of the population per annum over the United Kingdom. Reckoning consumption at the rate of 5·1 bushels per head per annum the first eight years, 5·5 the second eight, 5·6 the third eight, and 5·65 the next three years (instead of, as previously, 5·5 bushels over the last eleven years), the two estimates, recorded in Table XVIII., of the average produce per acre per annum over the United Kingdom, are then seen to be in very close agreement.

With reference to the circumstance that the average produce per acre, founded on the annual estimates, is slightly higher over the last two periods than that founded on consumption and imports, it must be borne in mind that the quantity of wheat consumed by farm-stock is an unknown and varying element, and either the estimate of the consumption per head of the population must be fixed to include the average consumption in other ways, or the annual estimates of produce per acre, and of the aggregate home produce founded upon them, should exceed those founded on consumption and imports. It is remarked that an increase of one-tenth of a bushel in the consumption per head per annum would, if derived from home produce, represent an increase of one bushel per acre per annum over the United Kingdom, assuming a population of 33,000,000, and an area under wheat of 3,300,000 acres—figures which closely represented the actual facts a very few years before 1880. With an increasing population and a diminishing area under wheat, such an assumed increase in consumption per head would, of course, correspond to more than a bushel per acre.

A most comprehensive and elaborate table presents in one view particulars of the home produce, imports, and consumption of wheat in the United Kingdom during each of the harvest years from 1852-3 to 1879-80. Space is too limited to permit of the reproduction of this valuable table, but in Table XIX. are given the details for each of the last eight or nine harvest years, together with averages of the four periods of eight years, of the two periods of sixteen years, and of the entire period of thirty-two years.

In discussing the facts set forth in the complete table, it is

TABLE XIX.—HOME PRODUCE, IMPORTS, AND CONSUMPTION OF WHEAT, 1852 TO 1887.

Harvest years, Sept. 1 to Aug. 31.	Estimated home produce.			Available for consumption.			Available for consumption per head.		
	Area under crop.	Average yield per acre.	Total home produce.	Home produce, less 2¼ bushels per acre for seed.	Imports less exports.	Total.	From home produce.	From imports.	Total.
	Acres.	Bushels.	Quarters.	Quarters.	Quarters.	Quarters.	Bushels.	Bushels.	Bushels.
1879-80.	3,047,752	15½	5,905,020	5,047,840	16,409,933	21,457,773	1·17	3·82	4·99
1880-81.	3,057,784	24½	9,364,464	8,504,462	16,182,210	24,686,672	1·95	3·72	5·67
1881-82.	2,960,066	24	8,880,198	8,047,679	17,200,108	25,247,787	1·83	3·91	5·74
1882-83.	3,157,924	25⅝	10,115,225	9,227,059	19,982,162	29,209,221	2·08	4·50	6·58
1883-84.	2,707,949	28	9,477,822	8,616,211	15,815,878	24,432,089	1·92	3·53	5·45
1884-85.	2,744,928	29⅜	10,079,032	9,307,021	18,000,980	27,308,001	2·06	3·98	6·04
1885-86.	2,549,335	30¼	9,639,673	8,922,673	15,209,508	24,132,181	1·95	3·33	5·28
1886-87.	2,358,372	29¼	8,622,798	7,959,506	17,395,799	25,355,305	1·72	3·77	5·49
1887-88.	2,383,584	28⅜	8,454,275	(1) 7,858,379	—	—	—	—	—

Averages.

Harvest years, Sept. 1 to Aug. 31.	Estimated home produce.			Available for consumption.			Available for consumption per head.		
	Area under crop.	Average yield per acre.	Total home produce.	Home produce, less 2¼ bushels per acre for seed.	Imports less exports.	Total.	From home produce.	From imports.	Total.
	Acres.	Bushels.	Quarters.	Quarters.	Quarters.	Quarters.	Bushels.	Bushels.	Bushels.
8 yrs., '52-60.	4,092,160	28	14,310,779	13,159,859	4,652,784	17,812,643	3·74	1·32	5·06
8 yrs., '60-68.	3,753,011	28½	13,309,247	12,253,712	8,097,761	20,351,473	3·30	2·19	5·49
8 yrs., '68-76.	3,788,131	26⅝	12,684,765	11,619,353	10,515,548	22,134,901	2·94	2·63	5·57
8 yrs., '76-84.	3,091,310	24⅞	9,636,682	8,754,751	15,781,483	24,536,234	2·03	3·64	5·67
16 yrs., '52-68.	3,922,586	28¼	13,810,013	12,706,785	6,375,273	19,082,058	3·53	1·75	5·28
16 yrs., '68-84.	3,439,721	$25\frac{3}{1}$	11,160,724	10,187,052	13,148,515	23,335,567	2·48	3·14	5·62
32 yrs., '52-84.	3,681,153	27	12,485,369	11,446,919	9,761,894	21,208,813	3·00	2·45	5·45

(1) Deducting only 2 bushels per acre for seed.

to be noticed that during the thirty-two years 1852-3 to 1883-4 inclusive, the area under wheat in the United Kingdom was reduced by about one-third. The average yield per acre is estimated at 28 bushels; but, owing to recent bad seasons, the average for the whole period of thirty-two years was only 27 bushels, that for the first sixteen years having been 28¼, but that for the second sixteen years only 25¾. Thus there has been a reduction not only in area under cultivation, but in yield per acre also. This latter, however, is probably temporary, whilst the reduction in area will doubtless continue. The great increase of population which has taken place within the period covered by the table has, of course, necessitated greatly increased consumption, and the comparison of the home production with the foreign importation, for successive periods, becomes of much interest. An inspection of the table will show that over the first eight years only one-fourth of the wheat consumed was obtained from foreign sources, whilst over the last eight years nearly two-thirds (15,781,483qrs.) of the entire consumption (24,536,234qrs.) was imported. It is probable that the home produce will still decline, consequent chiefly on reduction of area under cultivation; whilst, with increase of population, imports must increase. It may be seen that the total consumption of wheat per annum has increased from an average of about eighteen million quarters over the first eight years to upwards of twenty-four million quarters over the last eight of the thirty-two years—an increase of one-third. And whereas the average consumption per head per annum was under 5·1 bushels over the first eight years, it amounted to nearly 5·7 bushels over the last eight years.

Discussing this subject so recently as February, 1887, Sir John Lawes and Dr. Gilbert say: "In conclusion, we would remark that whilst 30 bushels per acre per annum is frequently assumed to be the average yield of the United Kingdom, our own estimate was, until recent years, 28¼ bushels; but the series of bad seasons has reduced the average, over the thirty-two years to 1883 inclusive, to 27 bushels. We nevertheless still adopt 28 bushels as the normal average yield. If, however, our estimate of consumption is, as alleged, too high, the average yield per acre would be lower, not higher, than our figures show. If, on the other hand, it were established that there is a large consumption by stock or otherwise, over and above our estimate of total consumption, it is obvious that our estimates of average yield per acre are, so far, too low."

The following statements are based upon the authors' second paper (1880), embracing three periods of eight years each, and an odd period of three years at the end. Of course, with regard to prices, most serious modification would be needed in order to bring the statistics up to the present date, the figures now to be mentioned coming down only to 1880. It appears, then, that the price of wheat per quarter declined from an average of 57*s.* 8*d.* over the first eight years (including the period of the Crimean War) to 49*s.* over the last three years (1876-77-78). The annual value of the home produce available for consumption declined from an average of nearly 38,000,000*l.* over the first eight years (1852-59) to less than 25,000,000*l.* over the last three years. The annual value of the imported wheat increased from an average of little more than 13,000,000*l.* over the first eight years to more than 33,000,000*l.* over the last three years. The annual value of the total wheat estimated to be consumed (1852 to 1878) ranged from under 40,000,000*l.* to more than 71,000,000*l.*, and it increased from an average of about 51,500,000*l.* over the first eight years, to more than 58,000,000*l.* over the last three years. The average annual cost of wheat per head was somewhat reduced in the later periods; it was 36*s.* 2*d.* over the twenty-seven years.

Over the whole period of thirty-two years (1852—1884), 44·6 per cent. of the wheat consumed was derived from imports; and the amount supplied from foreign sources has increased from an average of 26·5 per cent. of the total over the first eight years, to 64·3 per cent. of the total consumed over the fourth period of eight years. The least proportional quantity supplied from foreign sources in any one year was 15·4 per cent. in 1854-5 (2,983,000qrs. imports less exports against 19,410,742qrs. available for consumption), and the greatest proportional quantity supplied from foreign sources in any one year amounted to 76·5 per cent. in 1879-80 (16,409,933qrs. imports less exports against 21,457,773qrs. available for consumption). The amounts carried over from one harvest year to another will, of course, vary exceedingly according to circumstances, the influence of which cannot with any certainty be estimated. There is no reliable information as to the quantity of home-produced wheat held in farmers' hands, the quantity consumed by farm-stock or otherwise used, or the quantity of foreign wheat held over in the granaries. Then, again, the actual length of the period to be provided for, dependent on the earliness or the lateness of consecutive harvests, is a point not to be overlooked; it was estimated that, at the harvest of 1865, there still remained over from the extraordinary crop of 1863, and the abundant one of 1864, wheat equal to from one-third to one-half of an average crop, and that, even at the harvest of 1866 some of the crop of 1863 remained unthrashed. It may, indeed, be stated generally, that, as a rule, the excesses follow, as they should, seasons of high productiveness, whilst the deficiencies follow seasons of low productiveness.

VI.—EXPERIMENTS ON THE CONTINUOUS GROWTH OF BARLEY UPON THE SAME LAND FOR TWENTY YEARS.

The first twenty years' experiments on the continuous growth of barley extended from 1852 to 1871, and the results are given in the R.A.S. Journal, 1873. The land selected was a portion of that immediately adjoining the experimental wheat field. The wheat field has, however, as a matter of experiment, been artificially drained, whilst the barley field has not. The custom of the locality, in the case of land of similar quality, is to take the barley crop after roots fed off by sheep; but the soil is too heavy for this to be done with advantage in wet seasons. Nevertheless, good crops, both as regards quantity and quality, are so grown on such land in favourable seasons, and may, as a rule, be relied upon when barley is taken, not after folding, but after another corn crop. The object of the experiments was to obtain answers to such questions as the following: What are the grain-yielding capabilities of such land? What its powers of endurance? In what constituents, or class of constituents, does it soonest show signs of exhaustion? And how far will the answers arrived at on these points in reference to it, accord with, or be a guide to, those which would apply to any large proportion of the arable land of Great Britain when farmed in the ordinary way, with rotation?

The previous history of the land was: 1847, Swedish turnips, with farmyard manure and superphosphate (the roots carted off); 1848, barley; 1849, clover; 1850, wheat 1851, barley, with sulphate of ammonia. Having thus grown two corn crops in succession, it was, agriculturally speaking, in a somewhat exhausted condition for the after-growth of grain, and would, in the course of ordinary practice, be re-manured before growing another crop. It was, therefore, in a suitable state for testing the effects of different manures upon the crop, and for showing, by the results, in what constituents, or class of constituents, the soil had, by previous cropping, become practically the most deficient.

The area of 4¼ acres was divided into twenty-four nearly squàre plots; most of these were exactly one-fifth of an acre each, but the remainder somewhat less. Two plots were left unmanured, one was dressed every year with farmyard manure, and others with different manures which, respectively, supplied certain constituents of farmyard manure, separately or in combination. The investigators maintain that comparative results obtained in this way are far better calculated to indicate in what constituent or constituents the soil is relatively deficient, so far as the available supply for the crop to be grown is concerned, than what is generally understood as an analysis of the soil. This, the synthetic, as distinguished from the analytic method, is capable of giving important and conclusive evidence as to the conditions and requirements of the growth of barley, as indeed of other crops.

The selection of manures for the experiments on barley was, in many respects, the same as that adopted for those on wheat. In reference to this point, Table XX. is instructive; it shows the probable average amounts of certain constituents in what may be taken as fairly corresponding crops of wheat and barley. The produce per acre assumed, for this purpose, is: Wheat, 30 bushels of 60lb. per bushel =1800lb., and 3000lb. straw=4800lb. total produce; Barley, 40 bushels of 52lb. per bushel=2080lb., and 2500lb. straw

=4580lb. total produce; which will contain, approximately, the following constituents:

TABLE XX.—NITROGEN AND ASH-CONSTITUENTS IN WHEAT AND BARLEY.

	In Grain.		In Straw.		In Total Produce.	
	Wheat.	Barley.	Wheat.	Barley.	Wheat.	Barley.
	lb.	lb.	lb.	lb.	lb.	lb.
Nitrogen	32	33	13	12	45	45
Phosphoric acid	16	17	7	5	23	22
Potash	9·5	11·5	20·5	18·5	30	30
Lime	1	1·5	9	10·5	10	12
Magnesia	3·5	4	3	2·5	6·5	6·5
Silica	0·5	12	99·5	63	100	75

It will be observed that most of the above constituents occur in nearly equal amount in either crop. The total barley crop, however, would remove rather more lime, but considerably less silica, than the wheat crop. But, looking to the grain alone, the barley is seen to remove considerably more silica, and rather more of each of the other constituents than the wheat. Therefore, where the grain only is sold, and the straw is returned to the land in due course as manure, the eventual loss to the soil would be upon the whole greater, especially in silica, by the growth of such a crop of barley than of such a crop of wheat. In the experiments under notice, however, both grain and straw are always removed from the land.

The exact quantities of manures applied on a given plot will be specified where necessary. The mineral or ash constituents were supplied in the following commercial forms: Potash, as sulphate of potash; soda, as sulphate of soda; magnesia, as sulphate of magnesia (Epsom salts); lime, as sulphate, phosphate, and superphosphate; phosphoric acid, as bone-ash, mixed with sulphuric acid in quantity sufficient to convert most of the insoluble earthy phosphate of lime into sulphate and soluble superphosphate of lime; sulphuric acid, in the phosphatic mixture just mentioned, in sulphates of potash, soda, and magnesia, in sulphate of ammonia, &c.; chlorine, in muriate of ammonia; silica, as artificial silicate of soda. Of other constituents, the nitrogen has been supplied as sulphate and muriate of ammonia; as nitrate of soda; in farmyard manure; in rape-cake. The non-nitrogenous organic matter, yielding by decomposition carbonic acid and other products, was supplied in farmyard manure, and in rape-cake. The artificial manure or mixture for each plot is ground up, or otherwise mixed, with a sufficient quantity of soil and turf-ashes to make it up to a convenient measure for uniform distribution over the land. The mixtures so prepared are, with proper precautions, sown broadcast by hand, it having been found that the application of an exact amount of manure, to a limited area of land, can be best accomplished in that way.

Passing now to the field results, the investigators have constructed tables showing the quantity and quality of the produce obtained in each one of the twenty seasons. It will suffice here, however, to reproduce only those tables showing the average results of the entire period, the results in the best season, and the results in the worst. The following are the numbers of the selected plots, with an account of the manures supplied, per acre, per annum:

Plots.

- 1 O. Unmanured.
- 7. 14 tons farmyard manure.
- 4 O. Mixed mineral manure alone.
- 1 A. 200lb. ammonia-salts alone.
- 4 A. Mixed mineral manure and 200lb. ammonia-salts.
- 4 A A. Mixed mineral manure and 400lb. ammonia-salts first six years, 200lb. ammonia-salts next ten years, 275lb. nitrate of soda last four years.
- 4 C. Mixed mineral manure and 2000lb. rape-cake first six years, 1000lb. rape-cake last fourteen years.

The farmyard manure was made in the open yard, and did not contain the dung of animals highly fed on purchased food. The mixed mineral manure was composed per acre per annum of—

200lb. sulphate of potash (300lb. the first six years).
100lb. sulphate of soda (200lb. the first six years).
100lb. sulphate of magnesia
200lb. bone ash.
150lb. sulphuric acid, sp. gr. 1·7. } Superphosphate of lime.

The ammonia-salts were formed of an equal mixture of the sulphate and muriate of ammonia of commerce.

In Table XXI. are recorded the average results of the twenty years :

TABLE XXI.—AVERAGE QUANTITY AND QUALITY OF BARLEY PER ACRE PER ANNUM ON SELECTED PLOTS ; TWENTY YEARS, 1852-1871.

Plots (manured as above).	Dressed grain.		Total grain.	Straw and chaff.	Total produce (grain and straw).	Grain to 100 straw.
	Quantity.	Weight per bushel.				
	Bushels.	lb.	lb.	cwt.	lb.	
1 O	20	52·3	1133	11¾	2454	86·6
7	48¼	54·3	2768	28¼	5933	88·5
4 O	27½	53·4	1550	14⅜	3162	96·4
1 A	32½	52·1	1840	18½	3919	89·2
4 A	46¼	54·0	2630	28½	5817	83·2
4 A A	49¾	53·4	2813	32⅜	6443	79·5
4 C	47⅜	53·6	2698	29½	6002	83·0

The significant fact may be noted that, over a period of twenty years in succession, ammonia-salts (1 A) alone gave an average, per acre per annum, of 5 bushels more grain, and of 4cwt. more straw, than the mixed mineral manure (4 O) alone. Again, the ammonia-salts and mixed mineral manure together (4 A) gave an average annual produce of about 19 bushels more grain, and 14cwt. more straw, than the mineral manure (4 O) alone; but only about 14 bushels more grain, and 10cwt. more straw, than the ammonia-salts (1 A) alone. Hence, in this, in an agricultural sense, already corn-exhausted soil, the available supply of nitrogen was much more readily exhausted than the available supply of mineral constituents, so far as the requirements for the growth of barley are concerned.

CHARACTERISTICS OF THE BEST AND WORST SEASONS OF THE TWENTY YEARS.

If space permitted of the presentation here of the tables showing each season's results, it would be necessary to bear in mind that, so far as the influence of *season* is concerned, the *quantity* of the produce depends greatly on the amount and the distribution of rain during the growing period; and the *quality* (proportion of grain and quality of grain) on a suitable adaptation of temperature. And, so far as the influence of *manures* is concerned, the *quantity* (luxuriance) depends greatly on the available supply of nitrogen within the soil, and the *quality* of the crop (tendency to form seed and to ripen) on the available supply of mineral or ash constituents.

In no two years during the entire period did one and the same manure yield precisely identical results both as to the quantity and the quality of its produce. Nor have the seasons which have been more or less favourable than the average for one description of manure been equally favourable or unfavourable for other descriptions. Of the twenty seasons, that of 1854 was upon the whole the most, and that of 1856 was upon the whole the least, productive. The results obtained in each season are stated in Table XXII., in which the same plots are selected as in Table XXI., though, in this case, the unmanured plot has been placed second, and the farmyard-manured first. The description and quantities of manures per acre have already been specified on page 90.

The remarkable contrasts afforded by this table will

TABLE XXII.—QUANTITY AND QUALITY OF BARLEY ON SELECTED PLOTS, IN THE LEAST, AND IN THE MOST, PRODUCTIVE SEASON OF THE TWENTY, 1852-1871.

Weight per Bushel of Dressed Grain.

Plots.	Least Productive Season, 1856.	Most Productive Season, 1854.	Excess of 1854 over 1856.
	lb.	lb.	lb.
7	47·1	53·9	6·8
1 O	49·1	53·6	4·5
4 O	47·0	54·0	7·0
1 A	48·5	53·6	5·1
4 A	46·4	54·3	7·9
4 A A	45·4	52·1	6·7
4 C	46·3	52·8	6·5

Total Grain per Acre, reckoned at 52lb. per bushel.

Plots.	Least Productive Season, 1856.	Most Productive Season, 1854.	Excess of 1854 over 1856.
	Bushels.	Bushels.	Bushels.
7	31⅞	60⅛	28¼
1 O	15⅝	37¾	22⅛
4 O	19⅝	45⅝	26
1 A	27½	53⅛	25⅝
4 A	30¾	66	35¼
4 A A	36¼	68	31¾
4 C	35⅜	65⅝	30¼

Straw (and chaff) per acre.

Plots.	Least Productive Season, 1856.	Most Productive Season, 1854.	Excess of 1854 over 1856.
	cwts.	cwts.	cwts.
7	19¾	37¼	17½
1 O	8¾	21¾	13
4 O	9⅜	23⅛	13¾
1 A	17⅛	30¼	13⅛
4 A	21¼	40½	19¼
4 A A	33	49	16
4 C	30½	42⅛	11⅝

Total produce (grain and straw) per acre.

Plots.	Least Productive Season, 1856.	Most Productive Season, 1854.	Excess of 1854 over 1856.
	lb.	lb.	lb.
7	3866	7298	3432
1 O	1797	4405	2608
4 O	2075	4969	2894
1 A	3347	6155	2808
4 A	3981	7958	3977
4 A A	5582	9026	3444
4 C	5257	8125	2868

become apparent on inspection, but it is worth noting that, with one and the same expenditure for manure, there was a difference in the quantity of produce obtained in the two seasons of from thirty to thirty-five bushels of grain (4 A, 4 A A 4 C), and in one case (4 A) of nearly a ton of straw, or not much less than would represent the average barley crop of many localities. It may further be remarked that, whilst the season of 1856 was far worse than that of 1853 as regards both the quantity and the quality of the barley crop, 1853 was, for the experimental wheat (which that year could not be sown until the spring), in every particular worse than 1856. Again, whilst 1854 was a decidedly more productive barley year than 1863, yielding under almost every condition of manuring not only more grain, but considerably more straw—in other words, a greater quantity of total produce, indicating greater luxuriance—1863 was, on the other hand, a considerably more productive wheat year than 1854, and especially so in grain. Both years were, however, remarkable for very large produce of both grain and straw, both of wheat and of barley.

The years next to 1854, in order of productiveness of barley were 1857 and 1864, which were very good wheat years also. The years next in order to 1856 in point of badness of barley crop were 1859, 1860, 1868, and 1870; the deficiency in the two last-mentioned years being due to summer heat and drought, but in the other two seasons to very opposite conditions. The characters of the selected seasons of 1854 and 1856 may now be usefully compared.

The very unusually productive season of 1854 was preceded by a very severe winter; March and April were upon the whole warmer than usual, but May, June, July, and August were pretty uniformly below the average temperature, whilst in March, April, June, and July there was a very considerable deficiency of rain, though more than the average number of rainy days. In May, however, there was about double the usual amount of rain, and an unusually large number of rainy days. In August, again, there was a full amount of rain, which, however, fell for the most part in heavy showers, and the month was upon the whole favourable for ripening and harvest. Thus, 1854 was characterised by prevailing low rather than high temperature, an abundance of rain at the period of early active growth (doubtless favouring root development), and again before harvest; but otherwise by dryness as well as coolness. It would seem, therefore, that the large produce was due to a sufficiency of moisture within the soil when most wanted, with, at other times, comparatively dry and temperate atmospheric conditions, resulting in a continuity of unchecked growth, rather than in very active luxuriance at intervals.

Contrasting with the foregoing the extremely unfavourable season of 1856, it appears that there had been some rough weather in the early part of the winter, but the later and greater part was upon the whole mild. March, April, and especially May, were colder than the average, whilst June, July, and August, though showing average day-temperatures fully as high as usual, were very changeable, and in June and July the nights were cold. In each month from January to July there was considerably more rain than in the corresponding months of 1854—in all nearly 6in. more; whilst in April there was an excess over the average, in May more than double the average, and in August again an excess. Generally, then, the season was very wet, with marked alternations of heat and cold, whilst it was, for the period of the year, the coldest during the time of the greatest excess of rain. Moreover, there were heavy rains, with considerable fluctuations of temperature, about the ripening and harvest period. The very bad result in this season would seem to be due, therefore, to an excess of rain, with, at the same time, great alternations of temperature during the most active periods of growth, entirely preventing continuity of progress; whilst the unhealthy plant thus produced was subjected to unfavourable maturing conditions.

Bearing in mind that both wheat and barley will flourish under very temperate conditions, it is worthy of remark that both 1854, the year of the best barley crop, and 1863, the year of the best wheat crop, in the Rothamsted experiments, were characterised by circumstances conducive to steady and unbroken accumulation, followed by favourable maturing conditions, rather than by individual periods of more than ordinarily active luxuriance.

AVERAGE YIELD OF BARLEY PER ACRE PER ANNUM FOR EACH DESCRIPTION OF MANURE.

The second section of the report of experiments on the growth of barley for twenty years in succession on the same land deals with the average annual produce by each description of manure employed. On the unmanured plot the average annual produce of barley over the twenty years was about twenty-one bushels of dressed grain, and 12cwt. of straw. The quality, as indicated by the weight per bushel of grain, was higher over the second than over the first period of ten years; but the quantity of both grain and straw was between 23 and 24 per cent. less over the second ten years. Compared with wheat grown for many years in succession without manure, barley gave an average of more grain, less straw, and nearly the same weight of gross produce (grain and straw together); but the barley fell off more in produce of grain, and about equally in straw, over the later years. Prior to the commencement of the experiments, the previous cropping had been:

Wheat Field.	Barley Field.
Turnips (dunged).	Turnips (dung and superphosphate) carted off.
Barley.	Barley.
Peas.	Clover.
Wheat.	Wheat.
Oats.	Barley (sulphate of ammonia).

It is possible, therefore, that there would be rather more *nitrogenous condition* to work out of the barley land than out of the wheat land, and tabulated results lead to the conclusion that the wheat will eventually maintain a somewhat higher total produce than the barley. This is what might be expected with the autumn-sown crop, with its longer period for root development, and consequent possession of a greater range of soil for the collection of food.

Farmyard manure, applied yearly for twenty years (Plot 7), gave an average annual produce of more than 48 bushels of grain and 28cwt. of straw. The weight per bushel, quantity of grain, and quantity of straw were all considerably higher over the second than over the first ten years. The manure probably supplied from three to four times as much nitrogen as any of the artificial fertilisers, and much more of carbonaceous organic matter, and of every other constituent of the crop, than was contained in the produce. It would leave a large residue of nitrogenous, carbonaceous, and other matters in the soil, which seem to be very slowly available for future crops; but the large accumulation of organic matter increases the porosity of the soil, and its capacity for the retention of moisture; and the crops are thereby rendered both less susceptible to injury from excess of rain, and more independent of drought. As without manure, so with farmyard manure, barley compared with wheat yielded, over a series of years, more grain, less straw, but nearly the same quantity of total produce (grain and straw together). This is remarkable when it is considered that the wheat is autumn sown and autumn manured, and the barley spring sown and spring manured. It is interesting to note that during the twenty years, 280 tons of farmyard manure, containing from 80 to 90 tons of dry, solid matter, were applied per acre; but the produce only amounted to $24\frac{3}{4}$ tons of grain and $28\frac{1}{4}$ tons of straw, or in all to only 53 tons; and the increase over the produce without manure was only about $14\frac{1}{8}$ tons of grain and $16\frac{1}{8}$ tons of straw, in all $30\frac{1}{4}$ tons of total increase, which certainly would contain less than one-third as much dry, solid matter as was supplied in the dung.

Mineral manures alone gave very poor crops, and the quantity of both grain and straw fell off considerably during the later years, but superphosphate of lime alone gave more than salts of potash, soda, and magnesia, and not much less than the mixture of all. It may be concluded that the soil was not relatively deficient in any of the mineral constituents which the manures supplied: and, from the falling off in the produce both without manure and with purely mineral manure, it is probable that the growth of the crop under such conditions is gradually exhausting the available nitrogen accumulated within the soil from previous cultivation, manuring, and cropping. Mixed mineral manure, containing salts of potash, soda, and magnesia, with superphosphate of lime, gave, of barley, much more grain, rather less straw, but considerably more total produce than of wheat. It is probable that, with the autumn manuring for the wheat, the various constituents are distributed by the rains, or enter into less soluble combinations, or both, during the winter; that hence there is less active root development in the upper and more highly nitrogenous layers of the soil in the spring, and that hence the barley is more rapidly exhausting the accumulated nitrogen of the surface soil than the wheat. The distinction between "condition" and "fertility" is well illustrated by the mineral-manured and by the unmanured plots, for it is apparent that the condition of the soil, as distinguished from its normal or natural fertility, is, at any rate, so far as available nitrogen is concerned, being gradually worked out by the growth of the crop.

Nitrogenous manures alone (ammonia-salts or nitrate of soda) gave much more barley than mineral manures alone; the produce declined much less in the later years; and for twenty years in succession even fair, though not large, crops were obtained. Whilst over the twenty years the average annual produce was, by the mixed mineral manure (4 O), only 27½ bushels of grain and 14⅜ cwt. of straw, that by the 200lb. of ammonia-salts (1 A) alone was 32½ bushels of grain and $18\frac{1}{2}$cwt. of straw. In other words, whilst the *increase* of produce by the mixed manure alone averaged, over twenty years, only $6\frac{1}{2}$ bushels of grain and $2\frac{1}{4}$ cwt. of straw per acre per annum, the increase by this comparatively small quantity of ammonia-salts alone averaged over the same period $11\frac{1}{2}$ bushels of grain and $6\frac{3}{8}$ cwt. of straw. Comparing the effects of ammonia-salts with those of the same quantity of nitrogen in nitrate of soda, the latter gave an average annual increase of $5\frac{1}{4}$ bushels of grain and $4\frac{5}{8}$cwt. of straw over the former. Owing to the greater solubility and more rapid distribution in the soil and subsoil of the nitrate or its products of decomposition, it is more liable to loss by drainage when there is an excess of rain. On the other hand, the subsoil in its case becomes more disintegrated, therefore more porous, more retentive of moisture in a favourable condition, and more permeable by the roots. It is probably in part due to this action that the effects of a given amount of nitrogen as nitrate of soda increase from year to year compared with those of an equivalent application as ammonia-salts. How much of the greater effect of the nitrate may be due to this action, and how much to the mineral manure which in the first year of the experiments was supplied to the nitrated plot, it is impossible to determine. The fact that fair crops were obtained by nitrogenous manures alone throughout the entire period is a striking illustration of the mineral resources of such a soil; and it shows that when in what may, in an agricultural sense, be called a corn-exhausted condition, it was deficient in available nitrogen relatively to available mineral constituents. Putting together the results obtained with minerals alone, and with nitrogenous manures alone, it must now be apparent that the exhaustion noticed in the former case was due to a deficiency of available nitrogen in the soil. It is, indeed, of no little interest to know that on a somewhat heavy soil, consisting of a somewhat heavy loam with a clayey subsoil, and of only moderate corn-yielding capabilities, purely mineral manures will not yield anything like a fair crop of wheat or barley; but that, on the same soil, a comparatively small quantity of purely nitrogenous manure has yielded, for twenty years in succession, not much less barley than the average crop of the country; and that a larger amount gave, over six consecutive seasons, considerably more than an average crop. This is knowledge, acquired of the available mineral resources of such a soil, which chemical analysis would not have afforded, and which supplies, if not examples for exact imitation, at any rate a very sound basis for deduction in regard to actual practice.

By ammonia-salts (200lb. per acre) and superphosphate of lime ($3\frac{1}{2}$cwt. per acre) together, an average produce of more than 47 bushels of dressed grain, and more than $27\frac{1}{2}$cwt. of straw, or considerably more than the average barley crop of the country, was obtained over twenty years in succession; and the produce of grain increased, and that of straw in a less degree diminished, giving a higher total produce during the later than the earlier years. Notwithstanding the great demand made upon the supplies of potash within the soil, by the growth of the crop for so many years, by ammonia-salts and superphosphate without potash, the addition of salts of potash, soda, and magnesia gave no further increase of grain, and very little of straw and total produce. The potash-yielding capabilities of such a soil, and the beneficial effects of the use of superphosphate with nitrogenous manures for spring-sown corn crops, are here strikingly illustrated.

When the same mixed mineral manure (300lb. the first six years, and afterwards 200lb., sulphate of potash; 200lb. the first six years, and afterwards 100lb., sulphate of soda; 100lb. sulphate of magnesia) and 200lb. of ammonia-salts were applied per acre per annum for twenty years, in the autumn for wheat and in the spring for barley, the barley gave more than one-half more grain, nearly one-sixth more straw, and nearly one-third more total produce than the wheat. When the same mineral manure was used with a larger quantity of ammonia-salts, the result was still in favour of the barley, but in a less degree than with the smaller amount.

After applying 400lb. of ammonia-salts per acre per annum to barley for six years, and then reducing the amount to 200lb., the plots so treated gave for ten years in succession more produce than those which had only received 200lb. annually from the commencement. From this it is inferred that the excessive supply of 400lb. had left a residue of nitrogen within the soil which was available for succeeding crops.

The experiments on barley with nitrate of soda and ammonia-salts respectively, do not happen to be exactly comparable with one another; but, so far as can be judged, a given amount of nitrogen as nitrate of soda yielded more produce than the same amount as ammonia-salts, and especially so in dry seasons. This is probably due to the greater solubility of the nitrate, or its products of decomposition, and to their action on the subsoil, disintegrating it and rendering it more porous; thus affording more surface for the absorption and retention of moisture and manure, and greater permeability to the roots, rendering the plants less dependent on the fall of rain during growth.

A table presenting the average annual produce by 275lb. nitrate of soda (containing the same quantity of nitrogen as 200lb. of ammonia-salts) per acre per annum, both alone and with mineral manure, during the four years 1868-71, brings out the remarkable fact that the average produce is almost identical by the nitrate alone and by the nitrate and mixed alkali-salts together. Though much higher, it is again almost identical by the nitrate and the superphosphate, and by the nitrate, superphosphate, and mixed alkali-salts. The little effect hitherto of the potash, soda, and magnesia-salts is here again illustrated.

Rape-cake is estimated to contain, on the average, about

4·75 per cent. of nitrogen. It also contains a large amount of carbonaceous organic matter, and about 8 per cent. of mineral matter. By the annual application of rape-cake, whether without or with the addition of mineral manures, more barley than the average crop of the country has been obtained; but, in proportion to the nitrogen it contained, less than by ammonia-salts or nitrate of soda. The nitrogen of the nitrogenous organic matter of rape-cake is much less rapidly available than that of ammonia-salts or nitrates; indeed, analysis of the soil has shown that the rape-cake has left a considerable residue of nitrogen near the surface.

Since, for twenty or more years in succession, ammonia-salts, or nitrate of soda, with mineral manure (without silica), have yielded considerably more of both wheat and barley than the average crops of the country, and more also than either farmyard manure or rape-cake, it follows that the return to the soil of carbonaceous organic matter as manure is unessential, so far as the successful growth of either of these crops is concerned.

Thus, from a comparison of the produce obtained by the different manures, it has been shown that carbonaceous organic matter, supplied so largely in farmyard manure and rape-cake, is, at any rate, not essential as manure for either wheat or barley; that mineral manures alone will not yield fair crops of either; that nitrogenous manures give much more produce than mineral manures alone; and that the mixture of nitrogenous and mineral manures will give full crops for many years in succession. In other words, the supply by manure of matter yielding, by decomposition, carbonic acid and other carbon compounds within the soil has little or no effect; mineral manures alone will not enable the growing plant to obtain sufficient nitrogen from the soil or the atmosphere. When nitrogen in an available form was liberally provided, the mineral constituents of the soil were insufficient for its full effect; but when so supplied, the mineral manures, which alone had little effect, greatly increased the efficacy of the supplied nitrogen. The general result is that, whilst it is essential that there should be a liberal provision of mineral constituents, the amount of produce is more dependent on the supply of *available nitrogen within the soil* than of any other constituent.

QUANTITY OF AMMONIA REQUIRED TO PRODUCE AN INCREASE OF ONE BUSHEL PER ACRE IN THE BARLEY CROP.

The third section of the report of experiments on the continuous growth of barley for twenty years in succession on the same land discusses the amount of ammonia in manure (or its equivalent of nitrogen in other forms) required to yield a given increase of grain (and its proportion of straw); also how much the quantity will vary, according to the amount applied per acre, to the supply of mineral constituents, and to the characters of the seasons. A comprehensive table is constructed to show the amount of ammonia—or of nitrogen in nitrate of soda, or in rape-cake, or in farmyard manure, reckoned as ammonia—required to yield one bushel (52lb.) of increase of barley grain, and its proportion of straw, under a great variety of conditions of manuring, and in each of the twenty seasons. In each case increase is calculated over the produce on the corresponding plot without nitrogenous manure, the increase on the nitrate of soda and the farmyard manure plots being taken over the mean unmanured produce.

One example in detail will suffice to indicate the kind of information deducible from the table, which is far too extensive to reproduce. Five plots each received 200lb. ammonia-salts per acre per annum for twenty years, but in other respects were variously treated as follows: (1) Without any mineral manure; (2) with superphosphate; (3) with sulphates of potash, soda, and magnesia;

(4) with superphosphate and sulphates of potash, soda, and magnesia; (5) with superphosphate and sulphate of potash. Taking the average for the twenty years in each case, the quantity of ammonia required to produce one bushel increase of barley, and its proportion of straw, was, on the three plots with superphosphate (plots 2, 4, and 5), 2·13lb., 2·41lb., and 2·10lb.; on Plot 3, with salts of potash, soda, and magnesia, without superphosphate, 3·59lb.; and on plot 1, without any mineral manure, 3·68lb. Thus, taking the mean of the three experiments with superphosphate, the amount of ammonia required was rather under 2¼lb.; but with the mixed alkali-salts without superphosphate, and without any mineral manure at all, it was between 3½lb. and 3¾lb. That is to say, a given amount of ammonia-salts was more than one and a half times as effective when there was a liberal provision of mineral constituents, but especially of phosphates, within the reach of the roots, than when there was not. Assuming that, with otherwise favourable soil conditions, and with an application of not more than 50lb. of ammonia per acre, an increase of one bushel of barley (52lb.) and its straw may, on the average of seasons, be obtained for every 2lb. to 2¼lb. of ammonia applied, still the table indicates that the amount may vary very greatly according to the characters of the seasons. Thus, on Plot 2, with superphosphate, only about 1½lb. was required in the favourable seasons of 1863 and 1869; but in the bad seasons of 1853 and 1856, 5·36lb. and 4·48lb. respectively were necessary.

Before briefly summarising the conclusions established in this section, one or two minor points demand notice. During the last eight years of the twenty, one or two series of plots, which otherwise were receiving the same manure, also received 400lb. of silicate of soda per acre per annum. Almost every year the eye detected a marked effect from the silicate on the plots where no superphosphate was used, but comparatively little, if any, on the plots with superphosphate. So striking was this result, that the silicate was analysed to ascertain whether it contained any superphosphate. It was found not to contain any; nor did it contain nitrate, or nitrogen in any other form. It is suggested that by the action of the alkaline silicate on the soil, otherwise locked-up phosphoric acid was rendered available for the plants. But it is possible that, when the superphosphate was used, a secondary result of its action within the soil was the liberation of silicates, which, without it, were not available in sufficient quantity; and hence the little effect of the direct supply of silicates where the superphosphate was used, and the marked effect where it was not employed. Another suggested explanation is, that when the acid phosphate and the alkaline silicate are mixed together, they are rendered comparatively insoluble and inactive. The result may perhaps be due in part to more than one of these actions. Another remarkable result was that after mineral manures once applied, nitrate of soda alone, for nineteen years in succession, yielded a result, in proportion to its nitrogen, comparatively little inferior to ammonia-salts used every year in conjunction with superphosphate, or with superphosphate and salts of potash, soda, and magnesia.

From a review of all the data brought forward in this section is drawn the practical conclusion that when an increase of barley is obtained by means of artificial manures, such as sulphate of ammonia, or nitrate of soda, or Peruvian guano, an increase of one bushel of grain (52lb.), and its proportion of straw (say 63lb.), may, taking the average of seasons, be calculated upon for every 2lb. to $2\frac{1}{4}$lb. of ammonia, or its equivalent of nitrogen (1·65 to 1·86lb.), supplied in the manure—provided the amount applied be not excessive, and provided there be no deficiency of mineral constituents within the soil. These conditions are fulfilled when barley, grown after dunged roots carted off, or after another corn crop, is manured by from $1\frac{1}{2}$cwt. to 2cwt. of sulphate of ammonia, or $1\frac{3}{4}$cwt. to $2\frac{1}{4}$cwt. of nitrate of soda, with 2cwt. to 3cwt. of superphosphate per acre; or, from 3cwt. to 4cwt. of Peruvian guano, containing 12 per cent. of ammonia, without superphosphate. But when rape-cake is used, rather more nitrogen in that form will be required to yield a given increase of the crop for which it is applied; a given amount of nitrogen costs more in rape-cake than in either sulphate of ammonia or nitrate of soda. When the increase is obtained by sheep-folding, or by farmyard manure, very much less will be obtained in the first crop, in proportion to the nitrogen contained in the manure.

These generalisations may be compared with corresponding ones, based on the continuous growth of wheat for twenty years on the same land. For wheat, as for barley, the quantity of increase obtained for a given amount of ammonia, or its equivalent of nitrogen, in manure, varies exceedingly according to the amount applied, to the provision of mineral constituents within the soil, and to the seasons. But, under the conditions most comparable with those of ordinary practice, approximately 5lb. of ammonia, or its equivalent of nitrogen, were on the average required to yield one bushel increase of wheat, and its proportion of straw. Now, one bushel of wheat may be reckoned to weigh 61lb., and its average proportion of straw 105lb. Thus, whilst from 2lb. to $2\frac{1}{4}$lb. of ammonia in manure will yield 52lb. of barley-grain, and 63lb. of straw (=115lb. total produce), it required 5lb. to yield 61lb. of wheat-grain, and 105lb. of straw (=166lb. total produce). It is clear that it required much more nitrogen in manure to yield a given amount of increase of produce when applied in the autumn for wheat, than when in the spring for barley.

EFFECTS OF THE UNEXHAUSTED RESIDUE OF MANURES.

The fourth section of the report is on the effects of the unexhausted residue from previous manuring upon succeeding crops, on the loss of constituents by drainage, and on some allied points. One example of the many brought under notice will suffice to show the kind of information it is sought to obtain under this head. Two plots, 4 A and 4 A A received the same amount and description of mineral manure every year from the commencement. In addition, 4 A received ammonia-salts at the rate of 200lb. per acre every year, but 4 A A 400lb., or double the amount the first six years, and only 200lb., or the same as 4 A, the next ten years. Any increase, therefore, on 4 A A over 4 A, during the ten years in which they both received the same amount of ammonia salts, may presumably be attributed to the extra amount applied to 4 A A during the first six years. Tabulated results show that, during the ten years, there was an excess of produce on 4 A A compared with 4 A, due to the unexhausted residue of the previous nitrogenous manuring, of nearly 28 bushels of grain, and just 28cwt. of straw, or an annual average of $2\frac{3}{4}$ bushels of grain and $2\frac{3}{4}$cwt. of straw. Moreover, the excess in the tenth year was almost exactly the same as the average of the ten years, showing that the residue was not even then exhausted. There was, then, in this case, a marked effect upon the succeeding barley crops from the extra ammonia-salts applied in the first six years. Similar experiments, with nitrogen supplied in the form of nitrate of soda, showed that, with the nitrate, as with the ammonia-salts, there was a somewhat lasting effect from the extra amount applied during the earlier years.

In this section there is discussed at considerable length the amount and destination of the nitrogen of the soil, and Table XXIII., page 108, which explains itself, supplies for comparison the results of experiments, not only on barley, but on wheat and oats.

It may be explained that the increase in the amount of nitrogen in the produce by the use of it in manure is, in the case of the artificial mixtures of nitrogenous and mineral manure, calculated over the amount determined in the produce by the corresponding mixed mineral manure without

TABLE XXIII.—NITROGEN RECOVERED, AND NOT RECOVERED, IN INCREASE OF PRODUCE, FOR 100 PARTS SUPPLIED IN MANURE.

Wheat—20 *years*, 1852-1871.

Plots.	Manures per Acre per annum.	For 100 nitrogen in manure. Recovered in Increase.	For 100 nitrogen in manure. Not Recovered in Increase.
6	Mix. min. man. and 200lb. amm. salts (= 41lb. nitrogen)	32·4	67·6
7	,, ,, 400lb. ,, ,, (= 82lb. ,,)	32·9	67·1
8	,, ,, 600lb. ,, ,, (=123lb. ,,)	31·5	68·5
16	,, ,, 800lb. (*a*) ,, ,, (=164lb. ,,)	28·5	71·5
9A	,, ,, 550lb. (*b*) nitrate soda (= 82lb. ,,)	45·3	54·7
2	14 tons farmyard manure every year	14·6	85·4

Barley—20 *years*, 1852-1871.

Plots.	Manures per Acre per annum.	For 100 nitrogen in manure. Recovered in Increase.	For 100 nitrogen in manure. Not Recovered in Increase.
4A	Mix. min. man. and 200lb. amm. salts (= 41lb. nitrogen)	48·1	51·9
4AA	,, ,, { 400lb. ,, ,, (= 82lb. ,,) 6 years; 200lb. ,, ,, (= 41lb. ,,) 10 ,,; 275lb. nitrate soda (= 41lb. ,,) 4 ,, }	49·8	50·2
4C	,, ,, { 2000lb. rape-cake (= 95lb. ,,) 6 ,,; 1000lb. ,, ,, (=47·5lb. ,,) 14 ,, }	36·3	63·7
7	14 tons farmyard manure every year	10·7	89·3

Oats—3 *years*, 1869-1871.

Plots.	Manures per Acre per annum.	For 100 nitrogen in manure. Recovered in Increase.	For 100 nitrogen in manure. Not Recovered in Increase.
4	Mix. min. man. and 400lb. amm. salts (=82lb. nitrogen)	51·9	48·1
6	,, ,, 550lb. nitrate soda (=82lb. ,,)	50·4	49·6

(*a*) 13 years only, 1852-1864. (*b*) 475lb. nitrate in 1852, 275lb. in 1853 and 1854, 550lb. each year afterwards.

ammonia. The increase in the produce of nitrogen by farmyard manure is also calculated over that by the purely mineral manure. An inspection of the table will show that when the more excessive amounts of ammonia-salts were applied for wheat, notably less than one-third of the supplied nitrogen was recovered, and the less the greater the excess. The general result is that with neither crop is the whole of the supplied nitrogen recovered in the increase of produce obtained; that when a given amount of ammonia-salts was applied, a much less proportion was recovered in wheat than in either barley or oats; but that, even with wheat, more was recovered when nitrate of soda was employed than when ammonia-salts were used. The nitrogen applied in the manure, but not recovered in the increase of crop, may be lost either by passing away in the drainage waters, or by accumulating within the soil in a state of combination or distribution unfavourable for being taken up by the immediately succeeding crop. The facts elucidated by this section of the investigation may now be briefly summarised.

When either ammonia-salts, or nitrate of soda, or nitrogenous organic manure in the form of rape-cake, or farmyard manure, was applied for either wheat or barley, a considerable proportion of the nitrogen so supplied remained unrecovered in the increase of the crop for which the manure was employed; nor was the whole recovered in many succeeding crops. When ammonia-salts were applied in the autumn for wheat, a much less percentage of their nitrogen was recovered in the increase of crop, than when they were applied in the spring for barley or for oats. Analyses of the soils to the depth of 27in. revealed a considerable accumulation, within that depth, of the nitrogen of manure which had not been recovered in the increase of the crop; but indicated that a still larger amount remained to be otherwise accounted for. Analyses of the drainage waters showed that they contained a large amount of nitrogen as nitrates; that the quantity of nitrates in the drainage was the greater, the greater the amount of ammonia-salts applied as manure; that (after autumn sowing) the quantity was very much greater in the winter than subsequently in the spring and summer; that, indeed, the winter drainage, after sowing ammonia-salts in the autumn, may often contain from two to three parts (and sometimes much more) of nitrogen (in the form of nitrates and nitrites) per 100,000 parts of water. Calculation showed that, for every one part of nitrogen per 100,000 parts of drainage, there would be a loss of 2¼lb. of nitrogen per acre for every inch of rain passing beyond the reach of the roots. Inasmuch as a given surface of soil possesses much less capacity of absorption for nitrate of soda, or its products of decomposition, than for the ammonia of ammonia-salts, it follows that heavy rains soon after sowing would carry away in the drainage water more nitrogen from a dressing of nitrate of soda than from an equivalent dressing of ammonia-salts In one case, after a heavy dressing of nitrate of soda in the spring, Dr. Voelcker examined the drainage waters, and found 5·83 parts of nitrogen per 100,000 of water, corresponding to a loss of 13lb. of nitrogen per acre, per inch of rain so passing. Owing to the much less loss by drainage in the case of spring than of winter sowing, there was not only more increase in the immediate crop from a given amount of nitrogen applied in the spring for barley (or oats) than in the autumn for wheat, but there was also much more effect upon succeeding crops, from the at first unrecovered amount, in the case of the barley than in that of the wheat. Respecting the fate of the nitrogen supplied as manure in ammonia-salts, or in nitrate of soda, it is probable that the whole of this element is either recovered in the immediate increase of crop, or retained in the soil in a very slowly available condition, or drained away and lost. Owing to the slow decomposition of the nitrogenous organic matter of rape-cake and farmyard manure, their nitrogen is less rapidly available than that of ammonia-salts or of nitrate of soda; but so far as could be judged from direct experiments on the point, it would appear to be, at the same time, less subject to loss by drainage. Certain important mineral or ash constituents of manures—potash and phosphoric acid, for example—are, at any rate, in the case of the heavier soils, almost wholly retained by them within the range of the roots; and they are found to be very lasting in their effects upon succeeding crops, provided there be a sufficient available supply of nitrogen within the soil.

THE EXPERIMENTS ON THE CONTINUOUS GROWTH OF BARLEY COMPARED WITH OTHER SIMILAR EXPERIMENTS.

As in the case of the wheat experiments, so with those on barley, it may reasonably be objected that results obtained on one field alone are scarcely susceptible of general application until they have received some degree of confirmation based on similar experiments on other land. The investigators have provided against this objection by means of two sets of experiments, in one of which barley was grown for three years in succession on a series of plots which had previously been differently manured, and had grown ten crops of turnips in succession; whilst, in the other, barley has been grown in four-course rotation, without manure, and with different descriptions of manure.

In the Barn Field, barley was grown for three years, after ten years (1843-52) of turnips. The average produce of turnips over the last eight years (1845-52) was:

	Roots.		Leaves.		Total.	
	Tons	cwt.	Tons	cwt.	Tons	cwt.
1. Mineral manure alone	7	9	1	10⅝	8	19⅝
2. Min. man. and ammonia-salts	10	4¾	3	3	13	7¾
3. Min. man. and rape-cake	10	19⅝	2	13¼	13	12⅞
4. Min. man., amm.-salts, and rape-cake	12	3⅞	4	7⅜	16	11¼

Thus No. 1 gave the smallest, and No. 4 the largest, produce. Table XXIV. records the total produce (grain and straw) in the three succeeding years during which barley was grown, and for comparison there is introduced in the top line the yield without manure in the second, third, and fourth of the twenty years in which barley was continuously grown in the Hoos Field.

TABLE XXIV.—YIELD OF BARLEY UNDER VARIOUS CONDITIONS.

Manures.	Produce (grain and straw) per acre, lb.			
	1853.	1854.	1855.	Average 3 years.
Hoos Field—				
Barley, without manure, after three corn crops.................	3467	4462	3923	3951
Barn Field—				
Barley, after 10 years turnips, manured as under:				
1. Mineral manures (last 8 years)..	2618	2474	2206	2432
2. Min. man. (8 years); ammonia-salts (6 years)	2864	2691	2331	2629
3. Min. man. (8 years); rape cake (6 years)......	3558	3171	2712	3147
4. Min. man. (8 years); amm.-salts and rape cake (6 years)..	3546	3136	2555	3079
5. Min. man. (8 years); amm.-salts for barley, 1854	(2618)	7377	2852	5114
6. Min. man. (8 years); nitrate soda, for barley, 1854, 1855...	(2618)	8005	4727	6366

The average number of bushels of grain yielded during the three years, 1853-55, was, on the unmanured plot in Hoos Field, $31\frac{3}{8}$; and on Nos. 1, 2, 3, 4, 5, 6, in Barn Field, it was 20, 22, $25\frac{3}{4}$, $25\frac{5}{8}$, $39\frac{1}{2}$, $47\frac{5}{8}$ bushels respectively. It appears, then, that the mineral-manured turnips were followed by three insignificant barley crops, much smaller than when barley was grown after three immediately preceding corn crops. In what constituent or constituents had the mineral-manured turnips so exhausted the soil as to bring it into a condition even far worse for the after-growth of barley than when (after clover) three white straw crops had been grown in succession—namely, wheat without manure, barley with sulphate of ammonia, and barley without manure? An examination of the manuring and the results in experiments 2, 3, 4, as shown in the table, can leave no doubt that the increased produce was due to an increased supply of available nitrogen within the soil where it had been applied in the manures for the turnips. Still, in neither case is the produce so great as without manure in Hoos Field, where the barley was grown after several previous corn crops. Experiments 5 and 6, however, afford conclusive evidence that it was of available nitrogen for the barley that the soil had become so exhausted by the growth of ten successive crops of turnips. It may be seen in the table that, in the year 1854, these two plots, by the simple addition of nitrogen in the manures, increased the total produce three to three and a half times.

Evidence of yet another kind indicates that it was of available nitrogen that the turnips had rendered the soil so deficient for the after-growth of barley. It may be assumed that an average of from 25lb. to 30lb. of nitrogen would be annually removed from the Rothamsted soil by wheat or barley grown year after year without nitrogenous manure. But it is estimated that from the mineral-manured turnip plots there were, over the ten years, more than 50lb. of nitrogen per acre per annum removed. After making every allowance, it may fairly be assumed that about one and a half times as much nitrogen was removed from the land for eight, if not for ten years, in succession, as would have been taken in an equal number of crops of wheat or barley grown without nitrogenous manure. No wonder, then, that considerably less barley was grown in three years, after a series of mineral-manured turnip crops, than was obtained in another field after a less number of corn crops. The results in Barn Field, moreover, afford a striking illustration of the dependence of the turnip plant on a supply of available nitrogen within the soil, and of its comparatively great power of exhausting it.

The experiments on barley in four-course rotation (turnips, barley, clover or beans, wheat) were commenced in Agdell Field in 1848, and have been continued ever since. The area, of about 2½ acres, was divided into three equal portions. One-third has been left entirely unmanured from the outset; one-third has been manured with superphosphate of lime alone once every four years—that is, for the turnip crop commencing each course; and one-third, also for the turnip crop only, with a complex manure, consisting of superphosphate of lime, salts of potash, soda, and magnesia, sulphate and muriate of ammonia, and rape cake. From half of each plot the whole turnip crop (roots and tops) was removed; on the other half the roots were consumed on the land by sheep, and the uneaten leaves spread and ploughed in. In the first course, clover was grown as the third crop; but in the second to the sixth courses, instead of clover, half of each plot was sown with beans, and the other half left fallow. The average produce of turnips per acre over the first five courses (the crop failing in the sixth, owing to drought) was—

	Roots.		Leaves.		Total.	
	Tons	cwt.	Tons	cwt.	Tons	cwt.
Without manure	1	6¾	0	10½	1	17¼
With superphosphate only..................	6	16½	1	8	8	4½
With mixed manure	12	2½	2	2½	14	5

Without manure, therefore, there was scarcely any produce of turnips; consequently, there was no exhaustion of the land by removal of the crop, so that it was, practically speaking, left fallow for the barley. With superphosphate alone only small crops of turnips were grown, especially in the later courses; still, much more was removed from the land than without manure; and as nothing was supplied besides what the superphosphate itself contained, the land was, so far as other constituents are concerned, left much more exhausted for the growth of the barley than without any manure whatever. With the mixed manure fair crops of turnips were removed in the earlier, but less in the later courses, and (excepting in the first year) there would remain in the land a considerable residue from the manures applied; and hence it would be left in a higher condition for the barley than after either the unmanured or the superphosphated turnips. Table XXV. shows the total produce (grain and straw) of barley in each of the successive courses, and also the average of the six courses; for comparison, the top line shows the produce in the same seasons of the unmanured plot in Hoos Field, where barley is grown year after year without manure:

TABLE XXV.—YIELD OF BARLEY UNDER ROTATION.

Manures.	Produce (grain and straw) per acre, lb.						
	1849.	1853.	1857.	1861.	1865.	1869.	Average.
Hoos Field— Barley, unmanured, after three corn crops	—	3467	3295	2107	2042	2016	2585
Agdell Field— Barley, in 4-course rotation:							
Unmanured, continuously	5656	4465	5337	4718	4182	3358	4619
Superphosphate, for turnips only	3841	3560	3076	3775	3394	3686	3555
Mixed manure, for turnips only.........	3794	4873	5168	7391	5148	5800	5363

The apparently anomalous results of the first year are chiefly attributable to the fact that there had been removed from the unmanured plot only about $3\frac{1}{4}$ tons of roots, and $2\frac{1}{4}$ tons of tops, but from the mixed manure plot nearly 11 tons of roots, and more than $7\frac{1}{2}$ tons of tops; in the manured plot, further, there would be left much less, if any, residue of manurial constituents for the barley of the first course, than for any of the subsequent courses. The table shows that the quantity of barley grown in rotation without manure is very much greater than that grown in succession without manure. Again (omitting the first year), the produce after the removal of the full-manured and larger crops of turnips was uniformly, and on the average, very much higher than after the removed superphosphated turnips, and also generally, and on the average, higher than after the unmanured turnips; this larger produce of barley, after the removal of the larger crop of turnips grown by the mixed manured, is doubtless due to the fact that there would still be a considerable residue of the manure left within the soil. The results of experiments already discussed have shown that a liberal supply of mineral constituents alone was insufficient to secure a fair crop of barley, but that the further addition of nitrogenous manure raised the produce to a maximum. It may, therefore, be concluded, in the case now under notice, that the larger produce of barley after the full-manured, than after the superphosphated or unmanured crops in rotation, was not attributable to any residue of mineral constituents alone which would remain after the removal of the highly manured roots; and that the larger produce after the unmanured than after the superphosphated turnips was not due to a less exhaustion or greater accumulation of available mineral constituents where the smaller crop of turnips was removed. In fact, as in other experiments, so also in these, in which barley was grown in rotation, and under three very different conditions as to manuring, the evidence is sufficiently conclusive, and therefore corroborative of that in the other cases, that an essential condition for the growth of a full crop of barley, whether in rotation or under less usual conditions, is a liberal supply of available nitrogen within the soil.

SUMMARY OF THE RESULTS OF TWENTY YEARS' EXPERIMENTS ON THE CONTINUOUS GROWTH OF BARLEY UPON THE SAME LAND.

It remains now to draw such general conclusions as seem warrantable from the results of the experiments on the continuous growth of barley on the same land, and to show the practical bearings of the results. The barley field immediately adjoins that devoted to the experiments on wheat, and has a soil and subsoil of similar general character, and described as a somewhat heavy loam, with a subsoil of raw yellowish-red clay, but resting in its turn upon chalk, which provides good natural drainage. Though, in wet seasons, such a soil is not well suited for the growth of the crop after roots fed on the land by sheep, as is the custom of the locality, yet the recorded results abundantly prove that, when grown under favourable conditions, large crops of barley, of good quality, may be obtained from such land. *Without manure,* the average produce over twenty years was 21 bushels of dressed barley grain, of 52⅓lb. per bushel, and 12cwt. of straw. Though the quantity fell off considerably, the quality was considerably higher over the second than over the first ten years. Compared with wheat without manure, barley gave more grain, less straw, but nearly the same quantity of total produce. It, however, fell off more in produce of grain, and about equally in straw, over the later years. *By farmyard manure,* the average annual produce was more than 48 bushels of dressed grain, of 54⅓lb. per bushel, and 28cwt. of straw. The quantity of both grain and straw, and the quality of the grain, were considerably higher over the second than over the first ten years. As without manure, so with farmyard manure, barley, compared with wheat, yielded more grain, less straw, but much about the same quantity of total produce. *Mineral manures alone* gave very poor crops, and the quantity of both grain and straw fell off considerably during the later years. With barley there was much more grain, rather less straw, but considerably more total produce than with wheat. *Nitrogenous manures alone* gave much more barley than mineral manures alone; the produce declined much less in the later years; and, for twenty years in succession, fair, though not full, crops were obtained. *Nitrogenous and mineral manures together* gave, for twenty years in succession on the same land, rather more of both grain and straw than farmyard manure, considerably more than the average barley crop of the country under rotation, and an average weight per bushel of between 53lb. and 54lb. With the same amount of nitrogen and the same mineral manure, applied for twenty years, in the autumn for wheat and in the spring for barley, the barley gave much more grain, more straw, and nearly one-third more total produce than the wheat. Thus, then, with barley as with wheat, mineral manures alone failed to enable the plant to obtain sufficient nitrogen and carbon to yield even a fair crop; the greater effect of nitrogenous manures alone showed that the soil, in its practically corn-exhausted condition, was relatively richer in available mineral constituents than in available nitrogen; and the generally greater effect by nitrogenous and mineral manures together than by farmyard manure—which contained not only very much more nitrogen, but a large amount of decomposing carbonaceous organic matter, and probably more of every mineral constituent than the crop—showed that the nitrogen of the farmyard manure was in a far less rapidly available condition, and that its supply of carbon was at any rate unessential.

Though it is a mere truism to assert that the growing plant must have within its reach a sufficiency of the mineral constituents of which it is to be built up, yet the results obtained with barley, as well as those with wheat, have shown that, whilst it is essential that there be a liberal provision of mineral constituents within the soil, the amount of produce is more dependent on the supply by manure of available nitrogen, than of any other constituent. The question has been discussed as to how much ammonia, or its equivalent of nitrogen in some other form, will, on the average, be required to yield a given amount of increase of wheat or barley grain, and its proportion of straw. It was concluded that, on the average, about 5lb. of ammonia (or its equivalent of nitrogen) were required to yield one bushel of increase of wheat, and its proportion of straw, whilst only 2lb. to 2¼lb. of ammonia are required to produce one bushel increase of barley, and its straw. In other words, whilst it required 5lb. of ammonia in manure to yield 61lb. of wheat grain, and 105lb. of straw = 166lb. of total produce, it only requires from 2lb. to 2¼lb. to yield 52lb. of barley grain and 63lb. of straw = 115lb. of total produce. Or, for the production of 100lb. increase of total produce of wheat, it required 3lb., and for the production of 100lb. increase of barley (containing a larger proportion of grain, but about the same amount of nitrogen), it required only from 1¾lb. to 2lb. of ammonia in manure; that is to say, it required much more ammonia to yield a given amount of increase when applied in the autumn for wheat, than when in the spring for barley.

In connection with the action of nitrate of soda, it must not be overlooked that a given surface of soil has much less power to retain either nitrate of soda, or other nitrates, than ammonia, and so far their nitrogen is, *cæteris paribus*, more liable to loss by drainage. Yet when frequently used on the same land, such was the effect of the nitrate, or of its products of decomposition, aided by increased development of root, in causing the disintegration, and so increasing the porosity and surface of the clay subsoil, that there would appear to have been not only a greater retention of moisture in an available form by the subsoil, rendering the growing crop more independent of drought, but also a greater retention of nitrates than would be anticipated considering their solubility, and hence a more lasting effect from previous applications than would otherwise be expected. On the other hand, where, as in the case of the experiments at Rothamsted, nitrate of soda has been used in large quantities so many years in succession, the surface soil has retained so much moisture as to be difficult to work after wet weather. It may be added that the greater liability to loss by drainage of the nitrogen, than of the more important mineral constituents of manure, is doubtless one factor in the explanation of the circumstance of the prevailing excess of available mineral constituents, relatively to available nitrogen, in soils generally, under the ordinary course of agriculture in this country.

It may be laid down as a general rule, applicable to the country at large, that, on the heavier soils, full crops of barley of good quality may be grown with great certainty after a preceding corn crop, under the following conditions: The land should be got into good tilth. It should be ploughed up when dry, as soon as practicable after the removal of the preceding crop. In the spring it should be prepared for sowing by ploughing or scuffling as early in March as possible, if sufficiently dry. The artificial manure employed should contain nitrogen, as ammonia or nitrate (or organic matter), and phosphates. From 40lb. to 50lb. of ammonia (or its equivalent of nitrogen as nitrate) should be applied per acre. These quantities would be supplied in $1\frac{1}{2}$cwt. to 2cwt. of sulphate of ammonia, or $1\frac{3}{4}$cwt. to $2\frac{1}{4}$cwt. of nitrate of soda. With either of these there should be employed 2cwt. to 3cwt. mineral superphosphate of lime. Rape cake is also a good manure for barley; from 6cwt. to 8cwt. would supply about as much nitrogen as would be equal to from 40lb. to 50lb. of ammonia. With this manure, as with guano, the addition of superphosphate is unnecessary. Whatever manure be used, it should be broken up, finely sifted, sown broadcast, and harrowed in with the seed.

Economy in the cost of the nitrogen is the essential point to be considered in the selection of the manure to be used. According to the experiments at Rothamsted, it would appear that, at equivalent prices, a given amount of nitrogen as nitrate of soda may in the long run be more effective than an equal amount as ammonia; for, contrary to the current opinion, the full effect of the nitrate was not obtained until it had been used for some years on the same plot. The liability to loss of the nitrogen of manure in drainage will vary very much according to the characters of the soil and subsoil, and of the season. But as it is much greater during the late autumn and winter months than in the spring and summer, nitrate of soda, sulphate of ammonia, or Peruvian guano should always be sown in the spring.

VII.—EXPERIMENTS ON THE CONTINUOUS GROWTH OF BARLEY UPON THE SAME LAND FOR THIRTY-TWO YEARS.

The experiments on the continuous growth of barley on the same land have now been in progress for nearly a second period of twenty years, and it is desirable to examine the results as nearly as possible down to date. Considering first the yields without manure and with farmyard manure for a period of thirty-two years (1852-1883), it appears that, without manure, the yield in two years—the third and fourth—was in each case over 30 bushels per acre; in six of the first thirteen years the produce was between 20 and 30 bushels, but it never afterwards reached 20 bushels; whilst in twenty-four out of the thirty-two years the yield was less than 20 bushels—in two of these it amounted to only 10 bushels, and in one year (1879) to only 6¼ bushels. The tabulated results indicate that, independent of the fluctuations due to season, there was a progressive decline due to exhaustion, notwithstanding that the last four years gave a higher average than any other four in the last sixteen years. It is further discoverable that, without manure, there is a decline in the produce of barley grain of 31·4 per cent. over the second sixteen years, compared with the first sixteen. This decline is considerably greater than was found in the case of wheat, a circumstance doubtless due to the shorter period of growth, and the greater dependence on the surface soil, in the case of barley, exhaustion being thereby sooner manifested.

With farmyard manure, as with no manure, there is very great fluctuation from year to year, according to season; but, instead of a gradual decline, there is over the later years an obvious increase in yield, due to the accumulation of the manure. There is, in fact, instead of a decline of 27·7 per cent., as in the case of the unmanured plot, an increase of 7·3 per cent. over the last twelve years, as compared with the first twenty, although the second period included a number of the worst seasons of the entire series. In four of the thirty-two years the farmyard manure gave more than 60 bushels of barley per acre, in thirteen years between 50 and 60 bushels, in ten between 40 and 50 bushels, and in no case below 30 bushels. The average yield was, over the first twenty years, $48\frac{1}{4}$ bushels, over the last twelve years, $51\frac{3}{4}$ bushels; and over the thirty-two years, $49\frac{1}{2}$ bushels, against $17\frac{7}{8}$ bushels without manure. These results were obtained by the unusual application of 14 tons farmyard manure per acre per annum for thirty-two years in succession. This manure supplied over 200lb. nitrogen per acre per annum, or a total of over 4000lb. nitrogen in the twenty years, at the end of which period it was estimated that not more than about 15 per cent. of this large amount of nitrogen had been removed in the increase of crop. Hence there was a great accumulation, as was proved by analysis, of nitrogen within the soil, so much so that it was calculated that, if there were no loss of nitrogen by drainage, by evolution of free nitrogen, or otherwise, and if the accumulated residue were as available as that which had already been effective, the produce should be maintained at the level of that of the first twenty years for not far short of 150 years more.

After the first twenty years the application of the farmyard manure was entirely stopped on half the plot, so that the results obtained might be compared with those on the still continuously manured half, and on the unmanured plot. The results prove that there is a general tendency to increase in yield where the application of the farmyard manure was continued, and to decrease where it was discontinued; indeed, during the last four of the twelve years the manure-residue half plot shows an average of about 24 bushels per acre per annum less than the half plot where the application was continued. The average yield per acre over the first twenty years under continuous manuring was $48\frac{1}{4}$ bushels, whilst over the succeeding twelve years it was, where the manuring was continued, $51\frac{3}{4}$ bushels, but where it was discontinued only $34\frac{3}{8}$ bushels, showing, therefore, an average annual deficiency, under the influence of the residue only, of $17\frac{3}{8}$ bushels, or of 33·6 per cent. Over the whole period of thirty-two years the total produce (grain and straw) was without manure less than 1 ton per acre per annum, whilst with the farmyard manure it was $2\frac{3}{4}$ tons, and in some years it reached from $3\frac{1}{2}$ to $3\frac{3}{4}$ tons. It must now be apparent that, whilst there were gradual exhaustion and reduction of produce without manure, there were gradual accumulation and increase of produce with the annual application of farmyard manure. But when the application was stopped, although the effect of the residue from the previous applications was very marked, it somewhat rapidly diminished, notwithstanding that calculation showed an enormous accumulation of nitrogen as well as of other constituents. Indeed, determinations of nitrogen in the surface soil, after the twenty years' application of farmyard manure, showed it to be nearly twice as high as on the unmanured plot. The very large amount that accumulates within the soil is in a very slowly available condition.

It is now necessary to consider what is the character of the exhaustion induced by the growth of the crop without manure; and to what constituent, or constituents, of farmyard manure its effects are mainly due. These questions are solved by examining the results obtained on the plots dressed with various purely mineral manures, purely nitrogenous manures, and combinations of the two. A general view of the effects of sixteen different conditions as to manuring is given in Table XXVI., which is a summary table, recording the average produce over thirty-two years, 1852-1883, on each of the sixteen plots. The first column shows the results for the four plots without nitrogenous manure, the second column those for the four plots with ammonia-salts equal to 43lb. nitrogen per acre per annum, the third those for the four plots with nitrate of soda, and the fourth those for the plots with rape-cake.

TABLE XXVI.—AVERAGE ANNUAL YIELD OF BARLEY UNDER SIXTEEN CONDITIONS OF MANURING,—THIRTY-TWO YEARS, 1852-1883.

	No Nitrogenous Manure.	200lb. Am.-salts=43lb. N.	275lb. Nitrate of Soda=43lb. N.	1000lb. Rape-cake=49lb. N.
Dressed Grain per Acre—Bushels.				
Without mineral manure	$17\frac{7}{8}$	$30\frac{3}{4}$	$34\frac{3}{8}$	$43\frac{1}{4}$
Superphosphate	23	45	47	$45\frac{1}{4}$
Sulphates of potash, soda, and magnesia...	$19\frac{3}{4}$	$33\frac{7}{8}$	$35\frac{1}{4}$	$41\frac{3}{4}$
Superphosphate, and sulphates of potash, soda, and magnesia	$24\frac{1}{4}$	$44\frac{7}{8}$	$47\frac{1}{2}$	$45\frac{5}{8}$
Straw per Acre—lb.				
Without mineral manure	1128	1909	2246	2789
Superphosphate	1293	2827	3127	2953
Sulphates of potash, soda, and magnesia...	1170	2151	2455	2792
Superphosphate, and sulphates of potash, soda, and magnesia	1380	3019	3348	3065
Total Produce (Grain and Straw) per Acre—lb.				
Without mineral manure	2136	3649	4189	5249
Superphosphate	2584	5374	5791	5532
Sulphates of potash, soda, and magnesia ...	2278	4063	4490	5175
Superphosphate, and sulphates of potash, soda, and magnesia	2739	5574	6042	5667

Referring first to the results without nitrogenous manure, the first column plainly shows the very marked effect of mineral manures containing phosphates as compared with those consisting of alkalies alone. The second column shows that ammonia-salts alone gave a great increase, which is somewhat enhanced by the addition of alkalies, but markedly so when phosphates are also applied. The plots referred to in the third column actually received ammonia-salts equal to 86lb. nitrogen the first six years, equal to 43lb. nitrogen the next ten years, and nitrate of soda equal to 43lb. nitrogen the last sixteen years. The increase here, brought about by use of the nitrate, is seen to be greater still, and is again by far the greater where the superphosphate is used. As the rape-cake itself contains phosphates, the construction to be placed upon the results in the fourth column is that the phosphate of the rape-cake was effective when none was otherwise supplied; but when it was so applied in addition, there was more effect with the nitrate, with its more rapidly available nitrogen, than with the rape-cake, with its greater actual amount of nitrogen, but in a less rapidly available condition.

Since nitrogenous manures alone had much more effect than mineral manures alone, it is obvious that the exhaustion induced by the continuous growth of the crops is characteristically that of nitrogen.

Both with and without nitrogenous supply, phosphates were more effective than potash salts, showing that the available store of phosphoric acid in the soil became deficient sooner than that of potash. With the shorter period of growth of barley than of wheat, and its greater proportion of surface-rooting, both nitrogenous and mineral exhaustion are sooner developed; and, so far as mineral exhaustion is concerned, the available supply of phosphoric acid was sooner exhausted than was that of potash. Indeed, in ordinary agricultural practice, it is clearly established that superphosphate is more effective with the spring-sown than with the autumn-sown cereals.

CHARACTERISTICS OF THE BEST AND WORST SEASONS OF THE THIRTY-TWO YEARS.

Respecting the influence of season on the amounts of produce, the best seasons of the thirty-two were 1854 and 1857; the best season for wheat—1863—was also a very good year for barley. For almost all conditions of manuring, 1854 was the season of the highest total produce of barley, grain and straw together—that is, it was the season of the greatest luxuriance or vegetative activity; but 1857 was, especially for the highest manuring, the one of the highest produce of grain and of the highest quality or maturing of grain, as evidenced by the weight per bushel. Thus, 1854 was the highest for luxuriance and 1857 the highest for maturation of the crop. As for wheat, so for barley, 1879 was decidedly the worst season of the thirty-two. The contrast between the produce on the barley plots in the two very different good years and that in the worst season, 1879, is very striking, the difference amounting in several cases to as much as the average crop of the country.

Since seasons repeat themselves, the meteorological characters of 1854, 1857, and 1879, however briefly summarised, cannot fail to afford interesting comparisons. In 1854, the season of great luxuriance and high total produce, there was an excess of temperature in January, February, March, and April, with a deficiency of rain from November to April inclusive; but during May, June, and July, that is, the months of active above-ground growth, there were lower than the average temperatures, with a considerable excess of rain in May, and then a deficiency—conditions obviously favouring continued vegetation and slow maturation. In 1857 there was less excess of temperature and less than the average amount of rain to the end of April; then from May to August inclusive there was both considerable deficiency of rain and considerable excess of temperature, that is, there were throughout the period of active above-ground growth conditions favouring seeding tendency and maturation rather than luxuriance. Thus, then, the two good seasons were very different in their climatic characteristics, as they were in the character of their produce. The very bad season of 1879 registered much lower than average temperatures throughout the winter, spring, and summer, and even somewhat in the autumn, with, at the same time, great excess of rain from January to September inclusive, whilst both the deficiency of temperature and the excess of rain were very marked from April to August inclusive, that is, during the whole period of the above-ground growth and the ripening, if such it may be called, of the crop, for in many cases the weight per bushel was less than 50lb., whilst the amounts of produce were very greatly below the average.

VARIATIONS IN THE CHEMICAL COMPOSITION OF THE BARLEY CROP.

The influence of exhaustion of manures, and of variations of season, on the amount of produce of barley having been considered, it is pertinent next to inquire what influence these factors have upon the chemical composition of the produce. An examination of the results of analyses demonstrates the greater influence of variations of season than of manures on the composition of barley grain. There is much greater variation in the proportion of potash in the grain, in different seasons with the same manure, than there is with different manures, and further, the seasons showing the highest amount of potash are those of much higher maturing character than those with the lowest amounts. There is still greater, indeed enormous, variation in the amount of potash in the dry substance of the straw with the same manure in different seasons. There is also great variation according to manure—comparatively little in presence of a full supply, but considerable without manure, that is, with exhaustion.

As to the phosphoric acid in the grain, there is here again much more variation in different seasons with the same manure than with different manures. But whilst of potash there is the higher proportion in the better seasons, of phosphoric acid there are lower amounts in the better seasons. In fact, high amount of potash in the ash, and in the dry substance of the grain, is, as a rule, associated with high maturation, that is, with high proportion of starch, whilst high proportion of phosphoric acid is generally associated with low maturation and high proportion of nitrogen. The proportion of phosphoric acid in the straw also varies more with season than with manure, and it is the highest in the worst seasons.

With regard to the behaviour of soda, very much more of this ingredient was found in the crops grown without its supply in manure, but where potash was deficient, than where soda was annually supplied. This is strikingly shown in the average amounts per acre per annum in the total crops, grain and straw together. Thus, over a first period of ten years, 1852-1861, the average amounts of soda in the total crop were, without any supply in the manure of either potash, soda, or magnesia, 8·40lb., and with the supply of all three, only 3·84lb.; over a second period of ten years, 1862-1871, without the supply 15·21lb., and with the supply only 3·69lb.; and lastly, over a third period of five years, 1872-1876, without the supply 11·85lb., and with the supply only 3·27lb. Thus, then, not only was there much more soda taken up, or retained, by the plant where it was not supplied than where it was, but there was the more soda taken up the less the supply of potash.

The chief point of interest with reference to silica is, that its percentage in the ash of barley grain ranges from 17 to more than 20, whereas in the ash of wheat grain it ranges only from about 0·5 to about 1·5 per cent.; or, taking the proportion of silica to 1000 dry substance of grain, in barley it ranges from four to five parts, and in wheat only from about 0·1 to about 0·3 parts. This difference is obviously due to the chaff being adherent in the case of the barley grain, and not in that of the wheat grain, a circumstance leading to, as might be expected, less definiteness in the mineral composition of the grain of barley than in that of wheat.

There exists a popular notion that strength of straw is dependent on a high percentage of silica, but direct analytical results clearly show that the proportion of silica is, as a rule, lower, not higher in the straw of the better-grown and better-ripened crops—a result quite inconsistent with the usually accepted view that high quality and stiffness of straw depend on a high amount of silica. In fact, high proportion of silica means a relatively low proportion of organic substance produced. Nor can there be any doubt that strength of straw depends on the favourable development of the woody substance; and the more this is attained the more will the accumulated silica be, so to speak, diluted—in other words, show a lower proportion to the organic substance. A large proportion of brittle straw which breaks in plaiting has been characteristic of recent seasons of bad harvest, and these qualities are associated with low development of the woody matter, and high proportion of silica.

THE HOME PRODUCE AND THE IMPORTS OF BARLEY.

It is desirable now to inquire into such economic questions as refer to the extent of the area devoted to the growth of barley in the United Kingdom, the amount of our total annual imports, and from what countries these latter are chiefly derived. Table XXVII. shows the area under barley in the United Kingdom in each of the years 1873 to 1887, and also the total imports into the United Kingdom during the year succeeding each of the first fourteen of the fifteen harvests, reckoning from Sept. 1 to Aug. 31 in each case.

It is seen that since 1880, when the repeal of the malt tax took place, there has been, instead of an increase, a diminution in the home area under barley, accompanied by an increase in the imports. It would seem that the high duty served as a bounty on the higher qualities of the home growth, and that, when this was removed, the greater demand for medium qualities has given an advantage to the foreign producer. Nor has the removal of the duty led to an extended use of malt for feeding purposes, which was one of the main objects for which the repeal was strongly advocated by farmers.

TABLE XXVII.—ACREAGE AND IMPORTS OF BARLEY (UNITED KINGDOM).

Harvest Years.	Area.	Imports.	Harvest Years.	Area.	Imports.
	Acres.	Quarters.		Acres.	Quarters.
1873-4	2,574,529	2,391,785	1881-2	2,662,927	3,725,384
1874-5	2,507,130	3,667,174	1882-3	2,452,077	4,398,127
1875-6	2,751,362	2,272,081	1883-4	2,486,137	4,031,722
1876-7	2,762,263	3,684,725	1884-5	2,346,041	4,726,903
1877-8	2,652,300	3,976,384	1885-6	2,447,169	2,801,567
1878-9	2,722,879	2,798,494	1886-7	2,432,749	4,585,600
1879-80	2,931,809	3,467,147	1887-8	2,255,256	
1880-1	2,695,000	2,974,892			

Taking the sixteen years 1869-1884, Table XXVIII. shows: (1) the least annual import, (2) the greatest annual import, (3) the average annual import of barley into the United Kingdom from each of the countries named.

TABLE XXVIII.—IMPORTS OF BARLEY INTO THE UNITED KINGDOM.

Imported from :—	(1) Minimum annual import of 16 years, 1869-84.	(2) Maximum annual import of 16 years, 1869-84.	(3) Annual import, mean of 16 years, 1869-84.
	Quarters.	Quarters.	Quarters.
Russia	277,108 in 1869	1,544,774 in 1883	717,838
France	155,203 in 1870	1,731,259 in 1872	480,879
Germany	120,776 in 1876	1,008,144 in 1879	477,951
Turkey	23,391 in 1880	1,059,773 in 1877	453,393
Roumania.........	59,448 in 1877	1,601,596 in 1882	420,904
Denmark	63,525 in 1884	594.371 in 1879	358,847
Sweden	49,305 in 1884	155,872 in 1882	100,259
United States ...	—	303,677 in 1878	57,983
Egypt	—	76,361 in 1876	26,501
Chili	—	81,697 in 1884	16,274
Other countries..	34,342 in 1870	288,413 in 1884	133,917
Total............	2,020,863 in 1870	4,609,174 in 1883	3,244,746

Of recent years Russia has been to the United Kingdom the most important source of barley. France and Germany show fairly equal average amounts, but Germany has sent decidedly the more in the later years.

CULTIVATION OF WHEAT AND OF BARLEY COMPARED.

Lastly, comparing wheat with barley, it is apparent that the requirements of barley within the soil, and the susceptibility of this cereal to the external influence of season, are very similar to those of its near ally, wheat; but there are distinctions of result, dependent on differences in the habits of the plants, and in the conditions of their cultivation accordingly. Wheat is, as a rule, sown in the autumn, in a heavier and closer soil, and has four or five months in which to distribute its roots and get possession of a wide range of soil and subsoil, before barley is sown. Barley is sown in a lighter surface soil, and, with its short period for root development, relies in a much greater degree on the stores within the surface soil. Hence it is more susceptible to exhaustion of surface soil as to its nitrogenous, and especially as to its mineral supplies; and in the common practice of agriculture it is found to be more benefited by direct mineral manures, especially phosphatic manures, than is wheat when sown under equivalent soil conditions. The exhaustion induced by both crops is, however, characteristically that of available nitrogen; and when, under the ordinary conditions of manuring and cropping, artificial manuring is still required, nitrogenous manures are, as a rule, requisite for both crops, and for the spring-sown one, barley, superphosphate also.

VIII.—AGRICULTURAL RESULTS OF EXPERIMENTS ON THE MIXED HERBAGE OF PERMANENT MEADOW.

Meadow herbage offers to the agricultural investigator about as complex a subject for study as can well be imagined, and it is one the enormous importance and widespread application of which need no insistance. Some seven acres of the land in Rothamsted Park were, in 1856, set apart for "Experiments on the Mixed Herbage of Permanent Meadow" and were divided at first into nine and ultimately into twenty plots. Two of these have been left without manure from the commencement; two have received ordinary farmyard manure continuously; whilst the remainder have each received a different description of artificial or chemical manure, the same being, except in special cases, applied year after year on the same plot. The land has probably been laid down with grass for some centuries. No fresh seed has been artificially sown within the last fifty years certainly, nor is there any record of seed having been sown since the grass was first laid down. The land is a somewhat heavy loam, with a red clay subsoil resting upon chalk, and, although not artificially, is very well naturally, drained; it is a perfectly level area. For many years prior to 1851 the general mode of treatment was to dress occasionally with farmyard manure, road scrapings, and the like, and sometimes with guano or other purchased manure. One crop of hay was removed annually, weighing from $1\frac{1}{4}$ to 2 tons per acre; the second crop was always eaten off by sheep. In the spring of 1851, and of 1852, four separate acres of the allotted area were appropriated to the consumption by sheep of as many lots of differently manured turnips, 10 tons of the roots being eaten upon each acre. Neither these four acres nor the remainder were manured in any other way during those two seasons, nor were they manured at all in the three succeeding ones prior to the commencement of the experiments in 1856, at which time the character of the herbage appeared uniform over all the plots.

During the first nineteen years—1856-1874—the first crop only each year was mown, made into hay, removed from the land, and weighed. As a rule, the second crop on each plot was fed off by sheep, who received at the time no other food, the object being not to disturb the condition of the manuring. Frequently, however, the animals suffered considerably, and in 1866, 1870, 1873, and 1874 the second crops (and third, if any) were cut and spread on the respective plots. In the twentieth season—1875—the second crops being unusually heavy, and the weather favourable, they were for the first time cut, weighed as hay, and removed. In 1876 they were cut and spread on the plots. In 1877 and 1878 the second crops were again made into hay, weighed and removed. In 1879 the second crops were cut, sampled, carted, and weighed green; the dry matter in the weighed samples was determined, and the produce reckoned into hay by adding one-fourth to the calculated dry matter per acre. In 1880 and the following years the second crop was again made into hay and removed, and it is intended in future to adopt this plan, whenever the weather will permit.

The earlier reports of these experiments were communicated by the investigators to the Journal of the Royal Agricultural Society of England. They are six in number, and appeared, the first in 1858, and the sixth and last in 1863, and they extend altogether through 180 pages of the Journal.

For a reason which will presently appear, it is not necessary to examine each of these reports in detail; but, inasmuch as it will convey a good idea of the method and objects of the experiments, it seems desirable to briefly indicate the matters dealt with in each report. The first report is concerned solely with the produce of hay, estimated in cwts. per acre, yielded by each of the plots, there being seventeen of these at the time. The second report deals with the produce of constituents per acre on each plot, and contains estimates of the dry matter, the mineral matter, and the nitrogen carried away per acre by the crop on each plot, as well as estimates of the proportion of nitrogen recovered in increase for one hundred parts supplied in manures. The third report embraces a description of the plants, variously developed by different manures. These plants are appropriately arranged under the three heads of gramineous herbage, leguminous herbage, and miscellaneous herbage. This report further contains an estimate of the total yield of each kind of herbage.

The fourth report is concerned with the chemical composition of the hay, and contains estimates of the dry matter, of the constituents of the ash, of the nitrogen, of the woody fibre, and of the fatty matter. The fifth report, after noting that the most striking points so far brought out by the inquiry were those which illustrated the very great variation in the description and character of the plants developed by the different manures, proceeds to discuss (1) the general description and proportion per cent. of the different kinds of herbage (gramineous, leguminous, and miscellaneous), and the number of species in relation to the manures employed, and to the amounts of crop yielded; (2) the description and proportion per cent. of the predominating species in relation to the manures employed and to the amounts of crop yielded, details being added as to the names and proportion per cent. of the five predominating grasses, the two predominating leguminous plants, and the three predominating weeds on each plot; and (3) the tendency to the development of leafy or of stemmy produce, and the order of ripeness. This report closes with a summary of the most prominent results of the whole inquiry up to date (1863). The sixth and last report that appeared in the R.A.S. Journal gives an account of the produce of hay per acre, the chemical composition of the hay, and the amount of certain constituents removed from the land in the fourth, fifth, sixth, and seventh seasons of the experiments.

Since 1863 the R.A.S. Journal has been silent as to the results of this unique series of experiments on the herbage of permanent meadow; but on June 19, 1879, Dr. Lawes and Dr. Gilbert read before the Royal Society a paper bearing the title, "Agricultural, Botanical, and Chemical Results of Experiments on the Mixed Herbage of Permanent Meadow, conducted for more than Twenty Years in Succession on the Same Land.—Part I." The following year this communication was printed *in extenso* in the "Philosophical Transactions of the Royal Society," and occupies no less than 130 of the large quarto pages of that publication. Since it embraces the results of more than twenty years' observations, it was obviously unnecessary, as implied above, to enter at any length into a discussion of the first few years' results. The investigators arrange and consider the results obtained under three separate heads, dealing respectively with the agricultural, the botanical, and the chemical results. Part I., now under notice, treats principally of the agricultural results, and these we proceed to examine.

Without manure, the produce of hay has varied from about 8cwt. to nearly 39cwt. per acre, and the average yield has been about 23cwt. per acre per annum. But the plot most heavily artificially manured, and yielding the best, has given an average of about 64cwt. of hay per acre per annum, the extremes being 40cwt. and 80cwt. The results on the other differently manured plots vary greatly within these extremes. At the same time, the botanical composition of the herbage has varied most strikingly, so that, starting with some fifty species of plants on the unmanured land, any kind of manure induces a struggle which leads to a diminution of the number of species down to twenty, or even fewer, though it must not be overlooked that such diminution of specific forms may be quite compatible with an increase in the total yield of herbage. The subjoined details concerning the botanical composition of the herbage are derived from "Part II.—The Botanical Results" ("Philosophical Transactions," 1882), further information respecting which is given at the end of this volume.

Of Gramineæ the following twenty species have been identified upon the plots:—

GRAMINEÆ.

1.	Anthoxanthum odoratum, L.	Sweet scented vernal grass.
2.	Alopecurus pratensis, L. ...	Meadow foxtail.
3.	Agrostis vulgaris, With. ...	Creeping-rooted bent grass.
4.	Holcus lanatus, L.	Yorkshire fog.
5.	Avena elatior, L., or Arrhenatherum avenaceum, Beauv.	False oat grass.
6.	Avena pubescens, L.	Downy oat grass.
7.	Avena flavescens, L.	Yellow oat grass.
8.	Poa pratensis, L.	Smooth-stalked meadow grass.
9.	Poa trivialis, L.	Rough-stalked meadow grass.
10.	Dactylis glomerata, L.	Rough cocksfoot.
11.	Festuca ovina	Sheep's fescue.
12.	Lolium perenne, L.	Common rye grass.
13.	Briza media, L.	Common quaking grass.
14.	Cynosurus cristatus, L. ...	Dogstail.
15.	Festuca pratensis, Huds. ...	Meadow fescue.
16.	Bromus mollis, L....	Soft brome.
17.	Phleum pratense, L.	Timothy grass.
18.	Aira cæspitosa, L....	Tufted hair grass.
19.	Festuca elatior, L.	Tall fescue.
20.	Festuca loliacea, Huds. ...	Rye-leaved fescue.

Of the foregoing species the first twelve are of common occurrence upon all the plots. Nos. 13, 14, 15, 16, though very general, do not invariably occur upon each plot. Nos. 17 and 18 do not appear upon one-half, and in some years not one-fourth, of the plots. The last two species are extremely rare.

Of Leguminosæ, whilst ten species have been identified, there are only four of common occurrence upon the plots; these are:—

LEGUMINOSÆ.

Trifolium repens, L.	White or Dutch clover.
Trifolium pratense, L.	Purple or meadow clover.
Lotus corniculatus, L.	Common birdsfoot trefoil.
Lathyrus pratensis, L.	Yellow or meadow vetchling.

Of miscellaneous species as many as fifty-nine have been recorded. Below are mentioned those which commonly occur on more than half the plots, and they are arranged in the order of the frequency of their occurrence, each species indicated being more frequently recorded than any of those named after it. The upwards of forty remaining miscellaneous species are of decidedly rare and uncertain occurrence:—

MISCELLANEOUS SPECIES.

Rumex Acetosa, L.	Sorrel.
Conopodium denudatum, Koch., or Bunium flexuosum, With.	Earth nut.
Achillea Millefolium, L.	Milfoil or yarrow.
Pimpinella Saxifraga, L.	Burnet saxifrage.
Luzula campestris, Willd.	Field woodrush.
Ranunculus acris, L....	Upright buttercup.
Ranunculus bulbosus, L.	Bulbous crowfoot, or buttercup.
Ranunculus repens, L.	Creeping buttercup.
Centaurea nigra, L.	Black knapweed.
Cerastium triviale, L.	Mouse-ear chickweed.
Galium verum, L.	Yellow bedstraw or cheese rennet.
Stellaria graminea, L.	Lesser stitchwort.
Plantago lanceolata, L.	Ribwort, ribgrass, or plantain.
Veronica chamædrys, L.	Germander speedwell.
Taraxacum officinale, Wigg. ...	Dandelion.
Carex præcox, Jacq....	Vernal sedge.
Heracleum Sphondylium, L. ...	Cow-parsnip.

PLAN OF THE CONTINUOUS EXPERIMENTS ON MEADOW HERBAGE.

For the sake of comparison, it appears desirable to give a general description of the manuring of each plot, first premising that the different "mineral" or ash constituents were supplied in the substances designated in commerce as follows: *Potash*—as sulphate of potash (and in nitrate of potash). *Soda*—as sulphate of soda (and in nitrate of soda). *Magnesia*—as sulphate of magnesia (Epsom salts). *Lime*—as sulphate (gypsum), phosphate, and "superphosphate." *Phosphoric acid*—as bone ash, mixed with sulphuric acid in quantity sufficient to convert most of the insoluble phosphate of lime into sulphate and soluble "superphosphate" of lime. *Sulphuric acid*—in the above phosphatic mixture, in sulphates of potash, soda, and magnesia, and in sulphate of ammonia. *Chlorine*—in "muriate of ammonia" (chloride of ammonium, or sal ammoniac). *Silica*—as silicate of soda and silicate of lime (also in cut wheat straw). Other constituents have been artifically supplied as follows: *Nitrogen*—as sulphate of ammonia, as "muriate of ammonia," and as nitrate of soda. *Non-nitrogenous organic matter yielding, by decomposition, carbonic acid and other products*—in sawdust and in cut wheat straw. "Ammonia-salts," wherever referred to, are equal parts of sulphate and muriate of ammonia of commerce; and "superphosphate of lime" was always per acre, 200lb. bone-ash, 150lb. sulphuric acid (of specific gravity 1·7), and water. The artificial manures were mixed with ashes (burnt soil and turf) in quantity sufficient to make up a convenient measure for equal distribution over the land, and the mixtures were sown broadcast by hand, experience having proved this to be the best method on a limited area. The dressings of the plots were as follows:

Plot 1.—Farmyard manure and ammonia-salts, 8 years, 1856-63; ammonia-salts only 1864, and each year since.

Plot 2.—Farmyard manure, 8 years, 1856-63; unmanured 1864, and each year since.

Plot 3.—Unmanured, every year, 1856, and since.

Plot 4.—I. Sawdust (without effect), 3 years, 1856-58; superphosphate of lime, 1859, and each year since.

Plot 4.—II. Sawdust (without effect), 3 years, 1856-58;

superphosphate of lime and ammonia-salts, 1859, and each year since.

Plot 5.—Ammonia-salts alone, every year.

Plot 6.—Ammonia-salts 13 years, 1856-68 (with sawdust 7 years, without effect); sulphates of potash, soda, and magnesia, and superphosphate of lime, 1869, and each year since.

Plot 7.—Sulphates of potash, soda, and magnesia, and superphosphate of lime, every year.

Plot 8.—Same as plot 7 for 6 years, 1856-61; sulphates of soda and magnesia (without potash), and superphosphate of lime, 1862, and each year since; also sawdust the first 7 years (without effect).

Plot. 9.—Sulphates of potash, soda, and magnesia, and superphosphate of lime (as plot 7) and ammonia-salts, every year.

Plot 10.—Sulphates of potash, soda, and magnesia, and superphosphate of lime (as plots 7 and 8), and ammonia-salts, 6 years, 1856-61; sulphates of soda and magnesia (without potash) and superphosphate of lime (as plot 8), and ammonia-salts, 1862, and each year since; also sawdust the first 7 years (without effect).

Plot 11*a*.—Sulphates of potash, soda, and magnesia, and superphosphate of lime (as plots 7 and 9), every year; twice as much ammonia-salts as plot 9, 3 years, 1856-58; same ammonia-salts as plot 9, 3 years, 1859-61; double quantity again, 1862, and each year since.

Plot 11*b*.—The same as plot 11*a*, with the addition of a mixture of silicate of lime and silicate of soda, 9 years, 1862-70, and of silicate of soda only, 1871, and each year since.

Plot 12.—Unmanured, every year, 1856, and since (as plot 3).

Plot 13.—Sulphates of potash, soda, and magnesia, and superphosphate of lime, and ammonia-salts (as plot 9), and cut wheat straw, every year.

Plot 14.—Sulphates of potash, soda, and magnesia, and superphosphate of lime (as plots 7, 9, 11, and 13), and nitrate of soda containing nitrogen equal to that in the ammonia-salts of plots 5, 9, and 13, 1858, and each year since.

Plot 15.—Nitrate of soda alone, same quantity as plot 14, 18 years, 1858-75; no nitrate, but sulphates of potash, soda, and magnesia, and superphosphate of lime (as plots 7, 9, 11, 13, and 14), 1876, and each year since.

Plot 16.—Sulphates of potash, soda, and magnesia, and superphosphate of lime (as plots 7, 9, 11, 13 and 14), and half as much nitrate of soda as plot 14, 1858, and each year since.

Plot 17.—Nitrate of soda alone, same quantity as plot 16, 1858, and each year since.

Plot 18.—Mixture containing the potash, soda, lime, magnesia, phosphoric acid, silica, and nitrogen, of 1 ton of hay, also sulphuric acid and chlorine, 1865, and each year since.

Plot 19.—Nitrate of soda (same quantity as plots 16 and 17), sulphate of potash, containing the same quantity of potash as the nitrate of potash of plot 20, and superphosphate of lime, 1872, and each year since.

Plot 20.—Nitrate of potash, containing the same quantity of nitrogen, and the same quantity of potash, as the nitrate of soda and sulphate of potash of plot 19, and superphosphate of lime, 1872, and each year since.

A careful perusal and comparison of the preceding details will enable the reader to comprehend the scheme underlying the system of manuring, and to understand how the various dressings dovetail in with each other, so that the effects of each manure alone, and of two or more variously combined, are provided for.

In discussing the results on the various plots, it will be useful to have some standard of comparison, such as may be afforded between fair average yields of wheat, barley, and meadow hay. For this purpose the following yields per acre are assumed:

Wheat, 30 bushels=1800lb., and 3000lb. straw=4800lb. total produce.

Barley, 40 bushels=2080lb., and 2500lb. straw=4580lb. total produce.

Meadow hay, 1½ ton, or 3360lb.

Table XXIX. shows the average amounts of nitrogen, and of most of the mineral constituents, in the above quantities of wheat grain and straw, and barley grain and straw. Meadow hay varies so greatly in its botanical and chemical composition, according to soil, climate, and manuring, that it is necessary to take mean results.

TABLE XXIX.—COMPOSITION OF AVERAGE CROPS OF WHEAT, BARLEY, AND MEADOW HAY.

	In grain.		In straw.		In total produce.		1½ ton = 3360lb. meadow hay.			
	Wheat (1800lb.)	Barley (2080lb.)	Wheat (3000lb.)	Barley (2500lb.)	Wheat (4800lb.)	Barley (4580lb.)	A (8 years farmyard manure).	B (8 years without manure).	Mean of A. and B	Average of 39 analyses (E. Wolff).
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Nitrogen	32·0	33·0	13·0	12·0	45·0	45·0	40·8	47·2	44·0	52·0
Lime	1·0	1·5	7·5	9·0	8·5	10·5	27·1	35·2	31·2	33·8
Magnesia.........	3·5	4·0	3·0	2·5	6·5	6·5	7·4	9·4	8·4	12·8
Potash............	9·5	11·0	22·0	23·0	31·5	34·0	72·8	40·5	56·6	51·7
Soda	0·2	0·5	1·0	3·0	1·2	3·5	7·9	16·0	11·9	9·0
Phosphoric acid	15·0	16·5	6·0	4·5	21·0	21·0	16·4	11·0	13·7	16·2
Sulphuric acid	0·2	0·75	4·0	4·0	4·2	4·75	11·3	13·6	12·5	9·2
Chlorine	0·0	0·2	3·0	4·0	3·0	4·2	21·3	12·3	16·8	14·6
Silica	0·5	11·0	95·0	55·0	95·5	66·0	59·9	51·8	55·9	54·6

These figures, read from left to right, will be found most instructive. Assuming as the basis of comparison the mean composition of the manured and the unmanured hay, it is seen that a fairly good crop of hay will remove about one-third more nitrogen than the grain of a fairly good crop of wheat or barley, and practically the same amount as the total produce, grain and straw together, of either of the corn crops Of phosphoric acid, the hay crop will remove somewhat less than the grain alone, and only about two-thirds as much as the total produce of wheat or barley. Of potash, the assumed average hay crop will remove five or six times as much as the grain of either the wheat or the barley, and nearly twice as much as the total produce, grain and straw together. Of lime, soda, sulphuric acid, chlorine, and silica, the hay will remove many times more, and of magnesia much more, than either the wheat or the barley grain. Of lime, soda, sulphuric acid, and chlorine, the hay will also remove much more, and of magnesia more, than both grain and straw together. Of phosphoric acid and silica alone will the total produce of the corn crops remove more than the hay crops. Summing up the salient points, it is obvious that in Rothamsted Park, where the soil is a loam with a clay subsoil, the effect of the application of a complex fertiliser like farmyard manure, supplying as it doubtless does much more of all the mineral constituents than the crop takes up, is in a striking degree to increase the assimilation of potash—notably also that of phosphoric acid, and to some degree that of silica; much more chlorine is also taken up. Indeed, it will subsequently appear that the supply by manure of potash has a more marked effect on the quantity, and on the botanical and chemical character, of the herbage of the hay crop, than that of any other of the mineral or ash constituents.

RESULTS OBTAINED UPON THE VARIOUSLY MANURED PLOTS OF MEADOW LAND.

By dressing the several experimental plots of permanent grass land with different manures, and with different mixtures of manures, variations are induced in the character of the resultant herbage, the visible effect of which in the middle of summer may fairly be described as kaleidoscopic. To the practical man the nature and extent of these variations, as revealed by the gross test of the weighing machine, and by the subtler methods of the chemist and the botanist, are all important. These we proceed to discuss.

1. *Without Manure: Plots* 3 *and* 12.—Table XXX., recording the results on this plot, speaks for itself.

TABLE XXX.—AVERAGE PER ACRE PER ANNUM, WITHOUT MANURE.

	Average per Acre per Annum.		
	Plot 3.	Plot 12.	Mean.
HAY.	lb.	lb.	lb.
1st period, 10 years, 1856-65	2531	2808	2670
2nd period, 10 years, 1866-75	2236	2564	2400
Total period, 20 years, 1856-75	2383	2686	2535
2nd period, per cent. greater (+) or less than (—) 1st period	—11·7	— 8·7	—10·1
NITROGEN.			
1st period, 10 years, 1856-65	35·1	39·3	37·2
2nd period, 10 years, 1866-75	30·9	35·6	33·3
Total period, 20 years, 1856-75	33·0	37·5	35·3
2nd period, per cent. + or — 1st period	—12·0	— 9·4	—10·5
MINERAL MATTER (ASH).			
1st period, 10 years, 1856-65	148·5	161·7	155·1
2nd period, 10 years, 1866-75	126·1	143·2	134·6
Total period, 20 years, 1856-75	137·3	152·4	144·9
2nd period, per cent. + or — 1st period	—15·1	—11·4	—13·2

The uniform superiority of plot 12 over plot 3 will not escape notice. This was, at first, attributed to the fact that plot 12 is earlier sheltered from the evening sun, and therefore the less liable to suffer in dry weather. But the investigators were not content with this apparent reason, and therefore sampled the soil of the plots, in each case to a total depth of 54in., and from observations on the sections dug up, as well as from estimations of the nitrogen in every 9in. of depth, were led to conclude that a considerable part, at any rate, of plot 12 must have been made ground. Accordingly, it was decided that the results obtained on the unmanured plot 3 would provide fairer standards with which to compare those yielded on the manured plots than would the mean indications of the two unmanured plots. Hence, unless otherwise stated, all comparisons are made with the produce of the unmanured plot 3.

The reduction of produce on the continuous growth without manure is, apart from influences of the seasons, attributable in part to deficiency in available nitrogen, but probably in greater degree to that of an available supply of potash, of phosphoric acid, and of silica. In the absence of manure favouring any particular species or families of plants, no artificial struggle for existence was induced among the herbage, and the result was that a greater variety of species maintained their position than on any of the manured plots. The proportion of grasses was comparatively low; that of leguminous plants was fairly high; but the most marked characteristic was the large number, and high proportion by weight, of the miscellaneous species (weeds). Under this varied crop there is a much greater annual assimilation of nitrogen, and of some of the most important mineral constituents over a given area, than in an unmanured gramineous crop, such as wheat or barley, grown separately, on arable land.

2. *Ammonia-Salts Alone: Plot* 5.—The results shown in Table XXXI. were obtained by the annual application of ammonia-salts alone, at the rate of 400lb. per acre per annum, estimated to supply about 100lb. of ammonia, corresponding with about 82lb. of nitrogen; for comparison, the results on plot 3, without manure, are also given.

Compared with the produce without manure, ammonia-salts have given an average annual increase over twenty years of 563lb. of hay, or, in all, 11,260lb., or rather more than five tons, the extra demand for mineral constituents being met solely by the soil. But the falling off in increase as time went on is very marked. Actually less lime and potash were taken up with the ammonia than without manure, which appears due to the fact that, under the influence of the purely nitrogenous manure, various species which commanded a more extended range of soil than those which remained had disappeared. The total number of species became greatly reduced, grasses largely predominating. Thus, Festuca ovina (sheep's fescue) sometimes yielded more than half, and Agrostis vulgaris (fine bent) more than a quarter of the total produce; there was scarcely any leguminous herbage; the miscellaneous species were few, and added but little to the total weight, except Rumex Acetosa (sorrel), which was objectionably flourishing. Generally, the stunted foliage was of a very dark green colour, indicating a very high percentage of nitrogen in its dry substance, or rather a deficient assimilation of carbon in proportion to the nitrogen taken up.

TABLE XXXI.—AVERAGE PER ACRE PER ANNUM, BY 400LB. AMMONIA-SALTS ALONE; PLOT 5.

	Average per Acre per Annum.		
	Plot 3. Without manure.	Plot 5. Ammonia-salts alone.	Plot 5. + or − Plot 3.
HAY.	lb.	lb.	lb.
1st period, 10 years, 1856-65	2531	3420	+889
2nd period, 10 years, 1866-75	2236	2471	+235
Total period, 20 years, 1856-75	2383	2946	+563
2nd period, per cent. + or − 1st period	−11·7	−27·7	
NITROGEN.			
1st period	35·1	57·9	+22·8
2nd period	30·9	47·3	+16·4
Total period	33·0	52·6	+19·6
2nd period, per cent. + or − 1st period	−12·0	−18·3	
MINERAL MATTER (ASH).			
1st period	148·5	181·2	+32·7
2nd period	126·1	108·9	−17·2
Total period	137·3	145·1	+ 7·8
2nd period, + or − 1st period	−15·1	−39·9	

3. *Nitrate of soda alone*: *Plots* 15 *and* 17.—Here also are brought out the effects of a continuous supply of nitrogenous

without mineral manures, the nitrogen being, however, presented as nitrate instead of in the form of ammonia. Plot 15 received, for eighteen years, approximately the same amount of nitrogen per acre per annum as plot 5, but as nitrate of soda instead of as ammonia-salts; plot 17 has received annually half the quantity of nitrate. A slight difference in the periods will be noticed in the Table XXXII., page 148, in which the results are recorded.

Although plot 15 and plot 5 received the same amount of nitrogen per annum, namely, 82lb., yet, in the case in which this nitrogen was applied in the form of ammonia-salts (plot 5) there was an average annual increase of produce over the eighteen years of only 489lb., whilst with the same amount of nitrogen applied as nitrate of soda (plot 15) the corresponding increase was 1618lb., or 1129lb. more. In other words, whilst the ammonia-salts gave an average annual increase of little more than one-fifth over the unmanured produce, the nitrate gave more than one and two-thirds as much. The decline of produce in the second, as compared with the first period, was 10·3 per cent. without manure, 25·1 per cent. with ammonia-salts, and only 3·1 per cent. with the nitrate. The nitrate yielded one-fifth more nitrogen than the ammonia salts; whilst the decline of nitrogen in the second period was nearly 9 per cent. without manure, more than 17 per cent. with ammonia salts, and only $2\frac{1}{2}$ per cent. with the nitrate,

Striking as are these different effects of ammonia-salts and nitrate, they are even more marked in the amounts of mineral matter taken up. The quantities of mineral matter removed without manure and with ammonia-salts are almost identical, whereas the nitrate of soda crops took up half as much again. More lime, more magnesia, and considerably more potash, phosphoric acid, and silica were removed by the nitrate produce than by that of the ammonia-salts.

The explanation of these results must be sought in the herbage. Under the nitrate a greater total number of species

TABLE XXXII.—AVERAGE PER ACRE PER ANNUM, BY 550LB. AND 275LB. NITRATE OF SODA ALONE; PLOTS 15 AND 17.

	Average per Acre per annum.								
					Plot 15.		Plot 17.		
	Plot 3. Without Manure.	Plot 5. 400lb. Ammonia-Salts.	Plot 15. 550lb. Nitrate of Soda.	Plot 17. 275lb. Nitrate of Soda.	+or− Plot 3.	+or− Plot 5.	+or− Plot 3.	+or− Plot 5.	+or− Plot 15.
HAY.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
1st period, eight years, 1858-65	2492	3300	4038	3837	+1546	+ 738	+1345	+ 537	−201
2nd period, ten years, 1866-75	2236	2471	3913	3755	+1677	+1442	+1519	+1284	−158
Total period, eighteen years, 1858-75	2350	2839	3968	3792	+1618	+1129	+1442	+ 953	−176
2nd period, per cent. + or − 1st period	−10·3	−25·1	−3·1	−2·1					
NITROGEN.									
1st period	33·9	57·2	63·1	55·5	+ 29·2	+ 5·9	+ 21·6	− 1·7	− 7·6
2nd period	30·9	47·3	61·5	53·2	+ 30·6	+ 14·2	+ 22·3	+ 5·9	− 8·3
Total period	32·2	51·7	62·2	54·2	+ 30·0	+ 10·5	+ 22·0	+ 2·5	− 8·0
2nd period, per cent. + or − 1st period	− 8·9	−17·3	−2·5	−4·1					
MINERAL MATTER (ASH).									
1st period	145·8	168·2	225·9	223·8	+ 80·1	+ 57·7	+ 78·0	+ 55·6	− 2·1
2nd period	126·1	108·9	205·4	205·0	+ 79·3	+ 96·5	+ 78·9	+ 96·1	− 0·4
Total period	134·9	135·3	214·5	213·3	+ 79·6	+ 79·2	+ 78·4	+ 78·0	− 1·2
2nd period, per cent. + or − 1st period	−13·5	−35·3	−9·1	−8·4					

maintained a place than under the ammonia-salts. A greater variety, a better development, and consequently a wider and deeper distribution of the roots of the mixed herbage grown by the nitrate, gave it the command of a correspondingly increased range of soil and subsoil. Further, the nitrogen of nitrate of soda distributes more rapidly in the soil, both in the upper and the lower layers, and so root penetration into the latter is induced.

Lastly, the results show that the smaller amounts of nitrate acted more effectively than the larger dressing. Indeed, it would appear that the limit of growth under the influence of nitrate of soda alone—that is, without the aid of any artificial supply of mineral constituents—was nearly reached with the smaller quantity used. After eighteen years the heavier dose of nitrate was discontinued, and a mixed mineral manure (sulphates of potash, soda, and magnesia, and superphosphate of lime) was applied, but does not seem to have been instrumental in effecting the assimilation of any excess of nitrogen unused by previous crops; so that much of the nitrogen of the heavier dressing was probably lost in the drainage waters. But in the space of four years the herbage had much changed; the grasses became lighter in colour, and showed more tendency to form stem and to mature; leguminous species (especially Lathyrus pratensis) were gaining ground. The character of the miscellaneous herbage was also changing.

4. *Mixed Mineral Manure Alone*: *Plot* 7.—The dressing per acre per annum has been 300lb. sulphate of potash, 100lb. sulphate of soda (200lb. the first eight years), 100lb. sulphate of magnesia, and superphosphate of lime (200lb. bone ash, 150lb, sulphuric acid, sp. gr. 1·7); the results are shown in Table XXXIII., page 150.

Thus, mixed mineral manure alone gives considerably more produce than does nitrogen in the form of ammonia-salts, and nearly as much as nitrogen applied as nitrate of soda. Moreover, there is an increase in hay, in nitrogen, and in mineral matter during the second period as compared with the first. Yet it is an established fact that nitrogenous manures are specially effective in increasing the growth of gramineous crops grown separately on arable land, such as wheat, barley, or oats, though these only contain a comparatively small percentage of nitrogen, and assimilate a comparatively small amount of it over a given area when

TABLE XXXIII.—AVERAGE PER ACRE PER ANNUM, BY MIXED MINERAL MANURE ALONE; PLOT 7.

	Average per Acre per Annum.		
	Plot 3. Without Manure.	Plot 7. Mixed Mineral Manure.	Plot 7. + or − Plot 3.
HAY.	lb.	lb.	lb.
1st period, 10 years, 1856-65	2531	3797	+ 1266
2nd period, 10 years, 1866-75	2236	4118	+ 1882
Total period, 20 years, 1856-75	2383	3958	+ 1575
2nd period, per cent. + or − 1st period	−11·7	+ 8·5	
NITROGEN.			
1st period	35·1	55·2	+ 20·1
2nd period	30·9	58·0	+ 27·1
Total period	33·0	56·6	+ 23·6
2nd period, per cent. + or − 1st period	− 12·0	+ 5·1	
MINERAL MATTER (ASH).			
1st period	148·5	246·3	+ 97·8
2nd period	126·1	261·6	+ 135·5
Total period	137·3	254·0	+ 116·7
2nd period, per cent. + or − 1st period	−15·1	+ 6·3	

none is supplied in manure. The highly nitrogenous leguminous crops, on the other hand, such as beans, peas, clover, &c., are not characteristically benefited by the use of direct nitrogenous manures, though nitrates do act more favourably on them than ammonia-salts. Again, whilst, under equal conditions of soils and seasons, mineral manures alone increase comparatively little the gramineous crops grown separately, such manures, and especially potash manures, do in a striking degree increase the yield of leguminous crops so grown, and coincidently increase the amount of nitrogen they assimilate per acre. Consistently with this, the mixed mineral manure, containing potash, did very largely increase the leguminous growth on plot 7; some of the gramineous species, moreover, were increased to an extent hardly anticipated.

A table not reproduced here shows that over the twenty years more than half as much again gramineous herbage was grown by the purely mineral manure than by the unmanured plot 3. Though the leguminous herbage showed a less actual increase of weight than the gramineous, the proportional increase was much greater, there being four times as much grown with mineral manure as without manure. Of miscellaneous herbage there was very little increase, and a falling off in actual amount over the later years.

TABLE XXXIV.—NITROGEN AND ASH OF MEADOW HERBAGE.

	Per cent. Nitrogen.	Per cent. Mineral Matter (Ash).
Gramineous.		
Plot 3 (without manure).........	1·25	5·11
Plot 7 (mixed mineral manure)	1·18	5·64
Leguminous.		
Plot 3	2·31	6·32
Plot 7	2·31	6·81
Miscellaneous.		
Plot 3	1·45	7·30
Plot 7	1·32	8·74

Table XXXIV. shows the mean percentages of nitrogen and of mineral matter in the different kinds of herbage, dried as hay.

Basing the statement on the figures of Table XXXIV., it appears that, whilst the average annual amount of nitrogen in the gramineous herbage was 20lb. without, and 29·3lb. with, the manure, or 9·3lb. more with than without it, it was in the leguminous herbage only 4·2lb. without, but 18·2lb with, the manure, or 14·0lb. more with it than without it.

The much-debated question as to the source of this increased nitrogen of the leguminous herbage is here answered in favour of the soil, and, in the case of clover and beans at any rate, more probably the lower than the upper layers. In the unmanured herbage the deeper-rooting Lotus corniculatus (lesser bird's-foot trefoil) and Trifolium pratense (meadow clover) contributed most of the leguminous produce; but in the manured herbage it is the comparatively surface-rooting Lathyrus pratensis (meadow vetchling) that mainly contributes the leguminous increase.

The agricultural importance of the mode of root-distribution is further illustrated by gramineous plants. Spring-sown barley, which has but a short time in which to extend its roots, and to gain command of the resources of the soil, throws out a large quantity of fibres near the surface, and is more benefited by the action of direct mineral manures than is the autumn-sown wheat, which has four or five months longer for root-distribution, and is less dependent on the stores of the surface soil. Accordingly, the greatly increased gramineous yield in the mixed herbage by the purely mineral manure was almost exclusively due to the much denser growth, and much greater tendency to form stem and seed, of the creeping and surface-rooting Festuca ovina (sheep's fescue), Agrostis vulgaris (fine bent), and Holcus lanatus (Yorkshire fog).

How far is the increased growth of the grasses proper in the mixed herbage arising from an increased accumulation of combined nitrogen available to them in the upper layers of the soil—the result of the increased growth of, and accumulation by, the Leguminosæ—induced by the mineral manure? In other words, is there, where the plants are thus growing in association, a parallel action to that which takes place when they are grown in alternation (as wheat after clover, the clover crop having left the upper layers of the soil rich in nitrogen)? Analyses of the soils reveal a considerably lower percentage of nitrogen in the first 9in. of depth of the mineral manured plot 7 than in that of the unmanured plot 3, the difference being more than sufficient to account for the increased yield of nitrogen over the twenty years in both the gramineous and the leguminous herbage of plot 7. It would, in fact, appear that, under the influence of the mixed mineral manure alone, both the powers of collection, assimilation, and transformation of the plants themselves, have been considerably augmented, and the accumulated stores of nitrogen in the soil have been rendered more available.

With regard to mineral matter, plot 7, liberally supplied with mineral manures, yielded in its herbage over the first period nearly one and two-thirds as much, over the second period more than twice as much, and over the entire period nearly twice as much, as the unmanured plot 3. Potash and phosphoric acid rank first; of the former nearly three and a half times as much, and of the latter nearly three times as much, being taken up on the mineral-manured plot as on the unmanured plot.

The general result is that a mixed mineral manure alone has markedly influenced the description of plants developed, and has greatly favoured the tendency to form stem and seed —that is, to mature; it has also much increased the amount of total produce grown, and of nitrogen as well as mineral matter taken up. The evidence, so far, points to the potash of the manure as mainly conducive to these effects, the phosphoric acid probably coming second in order of importance.

5. *Superphosphate of Lime Alone: Plot* 4—I.—This plot has received phosphate alone every year from 1859. In each of the three preceding years (1856-7-8) it received sawdust (2000lb. per acre per annum), with the object of testing Leibig's assertion that it produced great effects by virtue of the solvent action exerted by the carbonic acid, yielded in decomposition, upon the mineral constituents of the soil.

Nevertheless, notwithstanding that each year's sawdust contained nitrogen equal to between 4lb. and 5lb per acre, the result was even less produce than without manure in each of the three seasons. Table XXXV. shows the average results on this plot.

TABLE XXXV.—AVERAGE PER ACRE PER ANNUM, BY SUPERPHOSPHATE OF LIME ALONE; PLOT 4—I.

	Average per Acre per Annum.				
	Plot 3. Without Manure.	Plot 7. Mixed Mineral Manure.	Plot 4. I. Superphosphate.	Plot 4. I. + or − Plot 3.	Plot 4. I. + or − Plot 7.
HAY.	lb.	lb.	lb.	lb.	lb.
1st period, 7 years, 1859-65......	2495	3828	2732	+ 237	− 1096
2nd period, 10 years, 1866-75 ...	2236	4118	2384	+ 148	− 1734
Total period, 17 years, 1859-75	2343	3999	2527	+ 184	− 1472
2nd period, per cent. + or − 1st period	−10·4	+ 7·6	−12·7		
NITROGEN.					
1st period	33·8	54·5	36·3	+ 2·5	− 18·2
2nd period	30·9	58·0	31·6	+ 0·7	− 26·4
Total period	32·1	56·5	33·5	+ 1·4	− 23·0
2nd period, per cent. + or − 1st period	− 8·6	+ 6·4	−12·9		
MINERAL MATTER (ASH).					
1st period	146·5	247·8	170·8	+ 24·3	− 77·0
2nd period	126·1	261·6	140·4	+ 14·3	−121·2
Total period	134·5	255·9	152·9	+ 18·4	−103·0
2nd period, per cent. + or − 1st period	−13·9	+ 5·6	−17·8		

Thus, the superphosphate plot gave more produce than the unmanured plot, but the increase was only small, whilst the actual produce per acre declined more than on the unmanured plot. On the other hand, superphosphate alone gave, over the total period, less than two-thirds as much hay as the mixed mineral manure.

The percentage reduction in annual yield of hay, of nitrogen, and of mineral matter, over the second period compared with the first, was greater with the superphosphate than without manure; whereas, with the mixed mineral manure there was not a reduction but an increase of all three during the second period.

The number and relative predominance of the plant species was much the same as without manure. The most noticeable changes were a rather greater weight of total gramineous herbage, due mainly to more of ripening tendency; a reduction in weight of Leguminosæ, with a prevalence of Lathyrus pratensis rather than that of Lotus corniculatus; and an increase in weight of miscellaneous herbage, with a greater prevalence especially of Ranunculus repens and R. bulbosus (buttercups), Achillea Millefolium (yarrow), and Rumex Acetosa (sorrel).

Of the constituents supplied in the superphosphate, a little more of lime and magnesia, once and a half as much sulphuric acid, and nearly twice as much phosphoric acid, were taken up under its influence as without manure. Of potash and silica very little more were taken up from the soil than without manure, but the increase of soda was somewhat greater.

The superphosphate enabled the plants to draw somewhat more largely on the resources of the soil, especially at first, but the small increased available supply under its influence rapidly diminished. A comparison of the produce by the superphosphate alone, with that by the mixed mineral manure, clearly shows that it was neither exclusively, nor even mainly, to the phosphoric acid which the latter contained that the results it yielded were due.

6. *Mixed mineral manure, with and without potash*: *Plots 7 and* 8.—During the first six years (1856-61), plots 7 and 8 each received the "mixed mineral manure," comprising superphosphate of lime, and sulphates of potash, soda, and magnesia, the only difference being that during those years, and in 1862, plot 8 also received 2000lb. of sawdust per acre per annum. From 1862 inclusive, plot 7 has continued to

receive the same mixed mineral manure, and plot 8 the same, excluding the sulphate of potash, but with an increased amount of sulphate of soda. The results are given in Table XXXVI.

TABLE XXXVI.—AVERAGE PER ACRE PER ANNUM, BY MIXED MINERAL MANURE, WITH AND WITHOUT POTASH; PLOTS 7 AND 8.

	Average per Acre per Annum.		
	Plot 7. Mineral Manure, including potash, every year.	Plot 8. Mineral Manure, including potash 6 years, without potash, 14 years.	Plot 8. + or − Plot 7.
HAY.	lb.	lb.	lb.
1st period, 6 years, 1856-61	3835	4027	+ 192
2nd period, 14 years, 1862-75	4011	3098	− 913
Total period, 20 years, 1856-75 ...	3958	3377	− 581
2nd period, per cent. + or − 1st period	+ 4·6	− 23·1	
NITROGEN.			
1st period	56·6	60·9	+ 4·3
2nd period	56·6	40·3	− 16·3
Total period	56·6	46·5	− 10·1
2nd period, per cent. + or − 1st period	0·0	− 33·8	
MINERAL MATTER (ASH).			
1st period	254·4	271·8	+ 17·4
2nd period	253·7	181·9	− 71·8
Total period	253·9	208·8	− 45·1
2nd period, per cent. + or − 1st period	− 0.3	− 33·1	

There is an average of rather more hay, and of rather more nitrogen and mineral matter taken up, on plot 8 than on plot 7, during the first six years. Whether this arose from the action of the sawdust is uncertain, but the increased amount of nitrogen taken up corresponded very closely with that contained in the sawdust. It has already been observed that sawdust alone gave no increase.

During the next fourteen years the relations are entirely reversed. There is an average produce of nearly one-fourth less hay, and of over one-fourth less nitrogen and mineral matter taken up, on plot 8 without than on plot 7 with potash, so that the falling off in the produce on the exclusion of potash was very great. The number of species remained about the same on the two plots, but the percentage of Leguminosæ has greatly diminished since the exclusion of potash. Without the potash the grasses became more leafy, less dense, and showed much less tendency to mature. The great difference in the amount of the total leguminous herbage on the two plots is due to the marked increase of the surface-rooting Lathyrus pratensis with the potash, and its greatly reduced growth without it. Of the deep-rooting and hardy Lotus corniculatus there was the more without the potash.

Excepting only silica and soda, less of every mineral constituent—potash, lime, magnesia, phosphoric acid, sulphuric acid—was taken up on plot 8 without potash than on plot 7 with the potash. In the dry substance the percentage of potash was less than two-thirds as high on plot 8 as on plot 7, though it was still much higher than on the unmanured plot, as also was the percentage of phosphoric acid.

The falling off in the total weight of produce, and in the description and character of development of the herbage on plot 8, must be attributed to the deficiency of available potash.

An interesting line of inquiry is suggested as to whether on plot 8 the potash taken up by the herbage was derived from the residue of the potash applied during the first six years, or was furnished directly by the soil. That certain soils do, as a matter of fact, retain a residue of supplied potash, and in a slowly available condition, for very many years, is conclusively proved by evidence of very different kinds. Thus, in the Rothamsted experiments, in which wheat has been grown continuously for many years on the same land, the effects of the residue of potash supplied more than twenty-eight years previously were still traceable in an increased produce, and in an increased amount of potash in the crop grown. Hermann von Liebig found the amounts of both potash and phosphoric acid considerably greater, particularly in the upper layers of the soil of this wheat field, the greater had been the previous supplies by manure. And Dr. Aug. Voelcker's analysis of drainage waters from different plots of the same field showed very much less loss of potash in that way than of either soda, lime, or magnesia, and also very much less of phosphoric acid than of sulphuric acid or of chlorine. There was, in fact, comparatively little loss by drainage of either potash or phosphoric acid.

To sum up the last three cases respecting the effects of the different mineral manures when used without artificial nitrogenous supply, the comparison of the results obtained without manure, with superphosphate alone, and with a mixed mineral manure with, and without, potash, brings clearly to view the much more striking influence of an increased supply of potash, than of lime, magnesia, soda, phosphoric acid, or sulphuric acid. It will be observed that this is quite consistent with the facts already set forth in Table XXIX., in regard to the mineral composition of the hay crop. It is true that when there was either a direct supply, or an available residue, of potash, more of the other constituents just enumerated was taken up, and even when superphosphate alone was used, considerably more phosphoric acid was taken up, but coincidently there was but little increase of produce, and very little increase in the amount of nitrogen assimilated.

Effect of Mixtures of Nitrogenous and Mineral Manures.—The results hitherto considered have been obtained either by nitrogenous manures alone or by mineral manures alone. It is now necessary to study the results following the application of mixtures of the two. The order of discussion will be —first, the effects of a given amount of nitrogen applied as ammonia-salts, then of double the quantity, then of the original amount applied as nitrate of soda, and then of half the quantity, also as nitrate, in each case used in conjunction with the same mixed mineral manure, including potash, as that applied to plot 7; and, following the same order as with the mineral manures used alone, comparison will then be made of the results obtained by the ammonia-salts alone, by the same with superphosphate of lime, with the mixed mineral manure including potash, and with the mixed mineral manure excluding potash.

TABLE XXXVII.—AVERAGE PER ACRE PER ANNUM, BY 400LB. AMMONIA-SALTS, WITH MIXED MINERAL MANURE CONTAINING POTASH; PLOT 9.

	Average per Acre per Annum.				
	Plot 5. Ammonia-salts alone.	Plot 7. Mineral Manure alone.	Plot 9. Ammonia-salts and Mineral Manure.	Plot 9. + or − Plot 5.	Plot 9. + or − Plot 7.
	lb.	lb.	lb.	lb.	lb.
HAY.					
1st period, 10 years, 1856-65 ...	3420	3797	6002	+ 2582	+ 2205
2nd period, 10 years, 1866-75 ...	2471	4118	5421	+ 2950	+ 1303
Total period, 20 years, 1856-75	2946	3958	5711	+ 2765	+ 1753
2nd period, per cent. + or − 1st period	−27·7	+8·5	− 9·7		
NITROGEN.					
1st period	57·9	55·2	75·7	+ 17·8	+ 20·5
2nd period	47·3	58·0	70·7	+ 23·4	+ 12·7
Total period	52·6	56·6	73·2	+ 20·6	+ 16·6
2nd period, per cent. + or − 1st period	−18·3	+5·1	− 6·6		
MINERAL MATTER (ASH).					
1st period	181·2	246·2	368·3	+187·1	+122·1
2nd period	108·9	261·6	301·0	+192·1	+ 39·4
Total period	145·1	254·0	334·6	+189·5	+ 80·6
2nd period, per cent. + or − 1st period	−39.9	+6·3	−18·3		

7. *400lb. Ammonia-Salts with Mixed Mineral Manure containing Potash: Plot* 9.—The average results on this plot are recorded in the foregoing Table XXXVII.

The result is, over the twenty years, considerably more than twice as much hay as without manure, nearly twice as much as by the same amount of ammonia-salts used alone, and nearly once and a half as much as by the same mineral manure used alone. During the second period, however, there was a falling off, as compared with the first, of nearly 10 per cent.

The average annual yield of nitrogen per acre was more than twice as much as without manure, more than once and a third as much as by the same amount of ammonia-salts alone, and nearly once and one-third as much as by the same mineral manures used alone. There was a decrease in the yield over the second ten years as compared with the first.

Of total mineral constituents about two and one-third times as much were taken up as either without manure, or with the ammonia-salts alone, and about once and a third as much as when the same mineral manure was used without ammonia-salts. There was a falling off of 18 per cent. in the second period as compared with the first.

In discussing the character of the herbage, it is necessary to bear in mind the corresponding results obtained (*a*) without manure, (*b*) with mixed mineral manure, (*c*) with ammonia-salts alone. On the plot now under notice, the mixture of nitrogenous and mineral manures gave rise to herbage still more gramineous than that produced by the ammonia-salts alone; in fact, the weight per acre of gramineous herbage averaged more than twice as much; the proportion of the produce due to both leguminous and miscellaneous species was also less, though the average weight per acre of both was rather more. But the botanical composition of the gramineous herbage was more varied. Thus, whilst Festuca ovina and Agrostis vulgaris contributed by far the larger proportion of the total herbage grown by ammonia-salts alone, and Anthoxanthum odoratum (sweet vernal), Holcus lanatus (Yorkshire fog), and Dactylis glomerata (cocksfoot) were only very moderately, and every other grass sparingly represented, yet, with the ammonia-salts and mineral manure together, both Festuca ovina and Agrostis were much less prominent, Holcus and Dactylis were nearly as much so, and Poa pratensis (smooth-stalked meadow-grass) was the most prominent of all. The character of development of the grasses was, moreover, totally different, there being a great tendency to form stem and seed and to mature. Under these conditions a much larger proportion of the supplied nitrogen was taken up than when the ammonia-salts were used alone. As it is probable that, even when used in conjunction with the mineral manure, not much more than half the supplied nitrogen was taken up, the reduction in produce over the second ten years would not seem to be connected with a deficiency of available nitrogen. The reduction in the amount of mineral matter taken up was greater than in that of the nitrogen, and yet calculation shows that more, and generally much more, of each constituent, excepting, of course, silica, was applied each year than was removed in the crop, so that there would be a constantly increasing residue accumulated during the later years in all cases in which there was no material loss by drainage. As will presently appear, however, when the same mineral manures were used with an increased amount of ammonia-salts, a larger amount of each of the mineral constituents, excepting lime, was taken up.

The reduced assimilation of both nitrogen and most of the mineral constituents over the second period was probably less connected with any real deficiency of either within the soil, in a condition capable of being yielded up, than with the description of plants favoured, and the character both of their underground and their above-ground development.

8. 400*lb.* *Ammonia-salts, with Mixed Mineral Manure containing Potash, and* 2000*lb. cut Wheat Straw : Plot* 13.—The only difference between this and the preceding case is the addition of 2000lb. of cut wheat straw per acre per annum, the object being to supply silica and carbonaceous

organic matter somewhat in the same condition as they are provided in farmyard manure. Table XXXVIII. shows the results.

TABLE XXXVIII.—AVERAGE PER ACRE PER ANNUM, BY 400LB. AMMONIA-SALTS, WITH MIXED MINERAL MANURE CONTAINING POTASH, AND 2000LB. CUT WHEAT STRAW; PLOT 13.

	Average per Acre per Annum.		
	Plot 9. Mineral Manure and 400lb. Ammonia-salts.	Plot 13. As Plot 9, and 2000lb. cut Wheat Straw.	Plot 13. + or − Plot 9.
HAY.	lb.	lb.	lb.
1st period, 10 years, 1856-65	6002	6186	+ 184
2nd period, 10 years, 1866-75	5421	6679	+1258
Total period, 20 years, 1856-75 ...	5711	6432	+ 721
2nd period, per cent. + or − 1st period	− 9·7	+8·0	
NITROGEN.			
1st period	75·7	79·5	+ 3·8
2nd period	70·7	87·3	+ 16·6
Total period	73·2	83·4	+ 10·2
2nd period, per cent. + or − 1st period	− 6·6	+9·8	
MINERAL MATTER (ASH).			
1st period	368·3	389·2	+ 20·9
2nd period	301·0	382·8	+ 81·8
Total period	334·6	386·0	+ 51·4
2nd period, per cent. + or − 1st period	−18·3	−1·6	

There is here considerably more average produce of hay, and more of nitrogen and mineral matter removed, over the twenty years, than by the same manures without the straw. And, instead of a reduction, there is a considerable increase in the yield of hay and of nitrogen, and a nearly equal yield of mineral matter, over the second ten years compared with the first.

It is not very easy to account for the greater yield where the cut straw was used, *i.e.*, of plot 13 over plot 9. Analyses of the respective soils reveal no essential differences, and, independently of the manure, the only known difference between plot 13 and plot 9 is that the former receives earlier afternoon shade.

On plot 13 the herbage has become even more markedly gramineous than on plot 9. Leguminosæ have almost equally disappeared on both; and the miscellaneous species have greatly decreased on both, Rumex Acetosa being the only prominent weed on either, Conopodium denudatum (Bunium flexuosum, earth-nut or pig-nut, an umbellifer) coming next. The increase on the straw plot was almost entirely composed of grass, which, compared with plot 9, contained very much more Dactylis glomerata, this, on plot 13, becoming the most prominent species; about the same proportion of Agrostis vulgaris, considerably less Holcus lanatus, very much less of Festuca ovina, and especially of Poa pratensis; but, on the other hand, a fair proportion of Alopecurus pratensis (meadow foxtail), which is scarcely represented on plot 9; whilst Avena pubescens, Avena flavescens (yellow oat grass), and Poa trivialis (rough stalked meadow grass) have gone down on both plots.

If all the nitrogen of the straw became available, it would supply about 9lb. per acre per annum, presumably a smaller proportion at first, and more and more each year. Hence there was on plot 13, compared with plot 9, no excess of yield of hay and of nitrogen in the earlier years, but a considerable excess over the latter half of the period; and there was an increase of about 10lb. of nitrogen per acre per annum over the twenty years. Probably the growing plants were enabled to avail themselves of more also of the other supplies of nitrogen within the soil.

There was some increase in the amounts taken up of all the mineral constituents, but the most marked was—of potash an average of about 23lb., of phosphoric acid about 4lb., and of chlorine about 8lb., with in each case more over the second period than over the first. There was, too, an average of about 8lb. more silica annually taken up on the straw plot, but less over the second period than the first.

Some of the increased luxuriance under the influence of the straw manuring is probably attributable to an increased supply of manurial constituents, and some to the mechanical effects (*e.g.*, the "mulching" effect, or protection given by the straw to the young shoots). And something is due, perhaps, to the greater powers of food collection within the soil of the species favoured.

9. 800*lb. Ammonia-salts with Mixed Mineral Manure containing Potash: Plots* 11*a and* 11*b.*—These plots show the effects of a considerably increased supply of ammonia-salts, used in conjunction with the same mixed mineral manure, including potash, as on plot 9. During the first three years double the amount, or 800lb. per acre, of ammonia-salts, containing about 200lb. of ammonia, equivalent to about 164lb. of nitrogen, was annually applied. This quantity, from its effects, appearing excessive, was then reduced to one-half, or to the same as on plot 9, for three years; but as it then appeared that the maximum growth possible was not attained, the quantity was again doubled, and has continued so. At the period of this change, too, *i.e.*, after the first six years, the plot (11) was divided, and to one-half, in addition to the ammonia-salts and the usual mixed mineral manure, artificial silicates were thenceforward applied; for nine years (1862-70), 200lb. of a crude silicate of lime, and 200lb. of a crude silicate of soda, and afterwards 400lb. of the silicate of soda, per acre per annum were employed. The results are summarised in Table XXXIX. opposite.

Thus an increased supply of ammonia-salts with the same mineral manures as on plot 9, has considerably increased the annual produce of hay, but in a much greater degree the assimilation of nitrogen, over a given area; and it has increased, in about the same proportion as the increase of hay, the amount of total mineral matter taken up over that on plot 9, where the same amount was applied by manure.

The addition of silicates during the last fourteen years of the twenty has further increased the amounts of hay yielded, and of nitrogen and mineral matter taken up.

TABLE XXXIX.—AVERAGE PER ACRE PER ANNUM, BY 800LB. (OR 400LB.) OF AMMONIA-SALTS, AND MIXED MINERAL MANURE, WITHOUT, AND WITH, THE ADDITION OF SILICATES; PLOTS 11*a*. AND 11*b*.

	Average per Acre per Annum.				
	Plot 9. Mineral Manure, and 400lb. Ammonia-salts.	Plot 11*a*. Mineral Manure, and 800lb.* Ammonia-salts.	Plot 11*b*. As Plot 11*a*, and Silicates	Plot 11*a*. + or − Plot 9.	Plot 11*b*. + or − Plot 11*a*.
HAY.	lb.	lb.	lb.	lb.	lb.
1st period, 10 years, 1856-65 ...	6002	6913	7077	+ 911	+ 164
2nd period, 10 years, 1866-75 ...	5421	6006	6909	+ 585	+ 903
Total period, 20 years, 1856-75	5711	6459	6993	+ 748	+ 534
2nd period, per cent. + or − 1st period	− 9·7	− 13·1	− 2·4		
NITROGEN.					
1st period	75·7	102·7	103·7	+ 27·0	+ 1·0
2nd period	70·7	103·5	111·7	+ 32·8	+ 8·2
Total period	73·2	103·1	107·7	+ 29·9	+ 4·6
2nd period, per cent. + or − 1st period	− 6·6	+ 0·8	+ 7·7		
MINERAL MATTER (ASH).					
1st period	368·3	420·7	435·9	+ 52·4	+ 15·2
2nd period	301·0	339·7	392·1	+ 38·7	+ 52·4
Total period	334·6	380·2	414·0	+ 45·6	+ 33·8
2nd period, per cent. + or − 1st period	− 18·3	− 19·3	− 10·1		

* 400lb. only in 1859, 1860, and 1861.

It is remarkable that, with the enormous amount of about 200lb. of ammonia, corresponding to about 164lb. of nitrogen, applied per acre per annum, for so many years, there appeared to be as large, if not a larger, proportion of the nitrogen supplied taken up by the growing herbage, as where only half the quantity was employed. There was, in fact, a proportionally much greater increase in the assimilation of nitrogen, than in the amount of total growth—that is, produce of hay—by doubling the application. In other words, the percentage of nitrogen in the produce was very much increased; it was, indeed, abnormally high, and indicates a deficient assimilation of other constituents in proportion to the nitrogen taken up.

An examination of the herbage shows that, with the combination of mineral manures and ammonia-salts, the greater the quantity of the latter the more nearly does the produce become exclusively gramineous, and the more does it consist of a few of the most freely growing grasses (Dactylis glomerata, Alopecurus pratensis, Agrostis vulgaris, Holcus lanatus, Avena elatior). These, too, take possession of the ground very much in tufts or patches, and grow coarse, strong seed-stems, and broad, flaggy, dark-green leaves. The herbage is, in fact, very coarse, often laid, and dead at the bottom before it is ripe; indeed, it generally matures irregularly and imperfectly, yielding hay of low quality, though, if the grass were fed off young, or cut green for feeding, it would probably be fairly good food.

The ash analyses reveal some striking differences in the mineral composition of the produce. There is a markedly lower percentage of lime, a lower percentage of magnesia, and, nothwithstanding the produce is so prominently gramineous, a lower percentage of silica, in the dry substance of the hay, than where the growth is less forced, and the herbage is at the same time more mixed. Of phosphoric acid, and especially of potash, there is, on the other hand, a considerably higher percentage in the dry substance of these coarse gramineous crops, as also there is of chlorine. The percentage, in the dry substance, of lime, magnesia, soda, sulphuric acid, and silica, has decreased over the later compared with the earlier years, whilst that of the potash and phosphoric acid (and also that of the chlorine) has increased over the later years. The percentage of lime especially has decreased the more, but that of the soda, sulphuric acid, and silica the less, the greater the amount of the ammonia-salts applied, and the coarser the herbage.

The only noticeable difference between the two plots 11 in the percentage mineral composition of the herbage is, that there is a slightly higher percentage of silica in that of the plot on which it was applied, and with this there is a less percentage of potash, and a less increased percentage of it over the later years. At the same time, there is a somewhat less excessive percentage of nitrogen where the silicates were used. In the presence of the excessive supply of nitrogen, and the increased activity of growth induced by it, the silicates of soda and lime employed were probably effective in other ways than merely as supplies of either silica, or soda, or lime, to the plant. The effect was probably due in part to reactions of the alkaline silicates within the soil; for, under their influence, there was more nitrogen, magnesia, potash, phosphoric acid, sulphuric acid, and chlorine, as well as more silica, lime, and soda, taken up; and, with these, more carbon assimilated.

Some useful facts may here be recalled. The dry matter of the miscellaneous species generally contains a higher percentage of mineral matter than that of the leguminous herbage, and the leguminous a higher percentage than that of the gramineous herbage; and the less matured the produce, the higher, as a rule, will be the percentage of mineral matter in its dry substance. Of the three, the ash of the leguminous herbage contains the highest, and that of the gramineous herbage the lowest percentage of lime, that of the miscellaneous being intermediate. On the other hand, the ash of the gramineous herbage is richest in potash, and it will be the richer in potash, and the less rich in lime, the greater the proportion of stem to leaf.

10. 550*lb. Nitrate of Soda, with Mixed Mineral Manure containing Potash*; *Plot* 14.—The comparison in this case (Table XL.) is with plot 9, which received mineral manures along with nitrogen applied as ammonia-salts. The experi-

ments with the nitrate were commenced two years later than those with the ammonia-salts, so that the periods are 8, 10, and 18, instead of 10, 10, and 20 years.

TABLE XL.—AVERAGE PER ACRE PER ANNUM, BY 550LB. NITRATE OF SODA, AND MIXED MINERAL MANURE, INCLUDING POTASH; PLOT 14.

	Average per Acre per Annum.		
	Plot 9. Mineral Manure and Ammonia-salts.	Plot 14. Mineral Manure and Nitrate of Soda.	Plot 14, + or − Plot 9.
HAY.	lb.	lb.	lb.
1st period, 8 years, 1858-65	5904	5944	+ 40
2nd period, 10 years, 1866-75	5421	6777	+1356
Total period, 18 years, 1858-75 ...	5636	6407	+ 771
2nd period, per cent. + or − 1st period	− 8·2	+14·0	
NITROGEN.			
1st period	75·4	67·6	− 7·8
2nd period	70·7	70·6	− 0·1
Total period	72·8	69·3	− 3·5
2nd period, per cent. + or − 1st period	− 6·2	+ 4·4	
MINERAL MATTER (ASH).			
1st period	356·1	357·2	+ 1·1
2nd period	301·0	373·2	+ 72·2
Total period	325·5	366·1	+ 40·6
2nd period, per cent. + or − 1st period	−15·5	+ 4·4	

As in the two cases of ammonia-salts and nitrate, each without mineral manure, so here, with mineral manure, there is a much greater produce of hay when the nitrogen is applied as nitrate of soda. There is also more mineral matter taken up under the influence of the nitrate, but rather less nitrogen; and whereas with the ammonia-salts there is a decline in annual yield of hay, and in the quantity of nitrogen and mineral matter taken up, over the second period compared with the first, there is, under the influence of the nitrate of soda, an increase in each of the three items over the later period.

In considering these results, special reference should be made to the droughty season of 1870, in which the fact that the nitrogen of nitrate of soda distributes much more rapidly through the soil than does that of ammonia-salts was in a marked degree illustrated.

As compared with plot 9, the nitrate plot (14) produces more Alopecurus, very much more Bromus mollis and Poa trivialis, and more Lolium perenne; but, on the other hand, very much less Poa pratensis and Festuca ovina, much less Agrostis, and, upon the whole, less Holcus, with, in all, more total Gramineæ. The nitrate plot is the richer in leguminous herbage, but this on both plots falls below 1 per cent. Of miscellaneous herbage, the ammonia-salts have generally yielded more than the nitrate, but latterly not so much. Rumex Acetosa is most prominent under the influence of the ammonia-salts, Conopodium denudatum and Achillea Millefolium coming next in order, and others occurring in quite immaterial amounts. On the nitrate plot also Rumex Acetosa comes to the front, but Anthriscus sylvestris (beaked parsley, an umbellifer) is about equally developed, and is increasing; Achillea Millefolium and Conopodium denudatum follow next; whilst Taraxacum officinale (dandelion) is more plentiful than on plot 9.

The striking differences in the amount of produce, in the amount of total mineral matter taken up, in the botanical composition of the herbage, in the character and distribution of the roots, and in the influence of the vegetation and the manures on the mechanical condition and on the chemical composition of the subsoil, according as the nitrogen is applied as ammonia-salts or as nitrate of soda, are associated with important differences in the chemical composition of the produce. As shown in Table XL., there was, with much more vegetable matter produced, even less nitrogen taken up and retained in the produce grown by the nitrate than in that by the ammonia-salts. The result was a much lower percentage of nitrogen in the dry matter of the produce of the nitrate plot, and, indeed, a much more normal percentage for this almost purely gramineous herbage. This lower percentage of nitrogen, with at the same time increased crop, implies, of course, an increased assimilation of carbon—that is to say, more activity of growth—in proportion to the nitrogen taken up. There was coincidently, more lime, magnesia, phosphoric acid, and sulphuric acid, considerably more silica, and very much more soda, taken up under the influence of the nitrate; but there was, on the other hand, considerably less potash, and very much less chlorine, taken up.

11. *275lb. Nitrate of Soda, with Mixed Mineral Manure containing Potash: Plot* 16.—Here the nitrate is only half as much as was applied on plot 14, and contains of course only half as much nitrogen as the ammonia-salts on plot 9. The experiments were commenced in 1858, so that the periods are 8, 10, and 18 years. Table XLI., opposite, records the results.

The most remarkable fact here brought out is that an average of only 6½lb. less nitrogen was annually removed than where the double amount of nitrate, supplying annually about 41lb. more nitrogen, was applied.

On both plots, 14 and 16, Alopecurus pratensis is plentiful and increasing. Plot 16 had a larger proportion of Holcus lanatus, and much more Avena flavescens, Agrostis vulgaris, and Festuca ovina; but there was a smaller proportion of Lolium perenne, less Dactylis glomerata, and very much less of both Poa trivialis and Bromus mollis; in all, a less proportion of total Gramineæ than with the double amount of nitrate. There was much more leguminous herbage, especially in the later years, and chiefly Lathyrus pratensis. There was also a larger, but a decreasing, proportion belonging to other orders. In fact plot 16, with less nitrate, produced a greater variety of grasses, but a less proportion of the more freely growing species; whilst it grew a greater number of species, and a considerably greater percentage by weight, of those belonging to the leguminous and miscellaneous orders.

TABLE XLI.—AVERAGE PER ACRE PER ANNUM, BY 275LB. NITRATE OF SODA, WITH MIXED MINERAL MANURE CONTAINING POTASH; PLOT 16.

	Average per Acre per Annum.		
	Plot 14. Mineral Manure and 550lb. Nitrate of Soda.	Plot 16. Mineral Manure and 275lb. Nitrate of Soda.	Plot 16. + or − Plot 14.
HAY.	lb.	lb.	lb.
1st period, 8 years, 1858-65	5944	5058	− 886
2nd period, 10 years, 1866-75	6777	5332	−1445
Total period, 18 years, 1858-75 ...	6407	5210	−1197
2nd period, per cent. + or − 1st period	+14·0	+5·4	
NITROGEN.			
1st period	67·6	63·0	− 4·6
2nd period	70·6	62·4	− 8·2
Total period	69·3	62·6	− 6·7
2nd period, per cent. + or − 1st period	+ 4·4	−1·0	
MINERAL MATTER (ASH).			
1st period	357·2	320·9	− 36·3
2nd period	373·2	307·9	− 65·3
Total period	366·1	313·7	− 52·4
2nd period, per cent. + or − 1st period	+ 4·4	−4·1	

With a greater number of species, possessing different habits of growth, there is a higher percentage of lime, an equal percentage of magnesia, a considerably higher percentage of potash and phosphoric acid, a higher percentage of sulphuric acid, about an equal percentage of chlorine and of silica, but considerably less of soda, in the dry substance of the produce grown by the smaller amount of nitrate of soda. And, reckoned per acre, there is very nearly as much lime, potash, and phosphoric acid, and not much less magnesia, though considerably less sulphuric acid, and chlorine, and very much less soda, and, at the same time, considerably less silica, gathered up under the influence of the smaller amount of nitrate.

Although the herbage of some of the best pastures of some of the best grazing districts of the country comprises but a small total number of species, it nevertheless includes a considerable proportion of other than gramineous species, and it is especially rich in Leguminosæ. Comparing the produce of the different experimental plots, however, the more complex the herbage, the higher, as a rule, is the quality of the hay, and it is especially so when leguminous species are in fair proportion; and, doubtless, the quality of the hay of plot 16 would be higher than that of any other of the plots yielding an equal weight of produce The result is, then, that with the mixed mineral manure, and a not excessive amount of nitrate of soda, there is both a large actual amount of produce, a large amount in proportion to the nitrate used, and a comparatively high quality of the hay.

12. 400*lb. Ammonia-salts, and Superphosphate of Lime: Plot* 4*b*.—As the experiment with ammonia-salts and superphosphate did not begin until the fourth year, the periods selected for the comparisons in Table XLII., on page 173, are seven, ten, and seventeen years.

Over the twenty years, ammonia-salts alone gave about one-fourth more produce than was obtained without manure, and the figures opposite show that, over the seven years of the comparative trial, the mixture of ammonia-salts and superphosphate gave over one-third more produce than the ammonia-salts alone. But superphosphate alone (plot 4*a*, Table XXXV., page 154) gave scarcely any more produce than the unmanured plot, doubtless owing to a deficiency of nitrogen available to such plants as were developed.

Not only was there much more total produce, but there was much more nitrogen and total mineral matter annually removed when the superphosphate as well as the ammonia-salts was used; but in both cases there was nearly the same percentage reduction in yield of hay, of nitrogen, and of mineral matter over the last ten compared with the first seven years (Table XXXI.) More lime, magnesia, phosphoric acid, and sulphuric

TABLE XLII.—AVERAGE PER ACRE PER ANNUM, BY 400LB. AMMONIA-SALTS, AND SUPERPHOSPHATE OF LIME; PLOT 4*b*.

	Average per Acre per Annum.		
	Plot 5. Ammonia-salts alone.	Plot 4*b*. Ammonia-salts and Superphosphate.	Plot 4*b*. + or − Plot 5.
HAY.	lb.	lb.	lb.
1st period, 7 years, 1859-65	3202	4440	+1238
2nd period, 10 years, 1866-75	2471	3414	+ 943
Total period, 17 years, 1859-75 ...	2772	3837	+1065
2nd period, per cent. + or − 1st period	−22·8	−23·1	
NITROGEN.			
1st period	56·0	67·6	+ 11·6
2nd period	47·3	57·8	+ 10·5
Total period	50·9	61·8	+ 10·9
2nd period, per cent. + or − 1st period	−15·5	−14·5	
MINERAL MATTER (ASH).			
1st period	163·0	250·0	+ 87·0
2nd period	108·9	162·3	+ 53·4
Total period	131·2	198·3	+ 67·1
2nd period, per cent. + or − 1st period	−33·2	−35·1	

acid were taken up than could be accounted for in the superphosphate supplied. There was also more potash, more soda, and more silica. The excess of all these mineral ingredients must have been supplied by the soil itself. In the second period, as compared with the first, there was a very great decline in the average annual amount taken up of almost every mineral constituent, except phosphoric acid and magnesia, in which the reduction was much less. Further, whilst in the dry substance there was (excepting lime) an abnormally high percentage of the mineral constituents supplied, there was an abnormally low percentage of those not supplied, again indicating that the point of exhaustion of available supply was reached. With this evidence of exhaustion of mineral matter, there was an abnormally high percentage of nitrogen in the dry substance of the produce of both plots, but especially in that by the ammonia-salts alone.

With this chemical evidence of repletion of nitrogenous, and deficiency of mineral supply, the botanical character of the herbage was equally significant. On both plots it became more and more gramineous, particularly with the superphosphate, where the number of species also declined more. On both plots Festuca ovina became by far the most prominent grass, constantly increasing, and in 1877 it made up more than half the total crop in each case. Agrostis vulgaris came next in abundance, and in 1877 the two grasses, Festuca ovina and Agrostis vulgaris, made up nearly 83 per cent. of the total produce grown by ammonia-salts alone, and within a fraction of 80 per cent. of that by ammonia-salts and superphosphate. On the plot with ammonia-salts alone, three other grasses, Anthoxanthum, Holcus, and Dactylis, together contributed about 10 per cent. more, and no other single grass as much as a quarter of 1 per cent. On the other plot (4*b*), Anthoxanthum, Alopecurus, Holcus, Avena elatior, Poa pratensis, and Dactylis, together contributed an additional 14 per cent., and no other grass more than a small fraction of 1 per cent.

Not only did the herbage, then, consist mainly of two grasses, but the one which took the lead, Festuca ovina, is the prevalent plant on poor common lands; and on both these plots both grasses showed very inferior characters of development. They consisted chiefly of very dark green leafy herbage, growing in patches or tufts, with very little tendency to produce stem and seed, and, particularly in dry seasons, dying at the bottom, without properly ripening, and always yielding a soft, woolly, and very inferior hay.

13. 400*lb. Ammonia-salts, and Mixed Mineral Manure, with and without Potash: Plots* 9 *and* 10.—During the first six years of the twenty both plots annually received 400lb. of ammonia-salts and the "mixed mineral manure," including potash. Plot 10 received 2000lb. sawdust per acre per annum during those six years, and again in the seventh year, but without effect. After the first six years both plots were manured as before, with the important exception that, from that date the potash was omitted from the manure of plot 10, and a somewhat increased amount of sulphate of soda was applied instead. The results are summarised in Table XLIII.

TABLE XLIII.—AVERAGE PER ACRE PER ANNUM, BY 400LB. AMMONIA-SALTS, AND MIXED MINERAL MANURE, WITH AND WITHOUT POTASH PLOTS 9 AND 10.

	Average per Acre per Annum.		
	Plot 9. With Potash 20 years.	Plot 10. With Potash 6 years, without 14 years.	Plot 10. +or−Plot 9.
HAY.	lb.	lb.	lb.
1st period, 6 years, 1856-61.........	6349	6223	−126
2nd period, 14 years, 1862-75	5438	4725	−713
Total period, 20 years, 1856-75 ...	5711	5174	−537
2nd period, per cent. + or − 1st period	−14·3	−24·1	
NITROGEN.			
1st period	78·7	73·3	− 5·4
2nd period	70·9	72·7	+ 1·8
Total period	73·2	72·9	− 0·3
2nd period, per cent. + or − 1st period	− 9·9	− 0·8	
MINERAL MATTER (ASH).			
1st period	406·8	419·8	+ 13·0
2nd period	303·7	243·8	− 59·9
Total period	334·6	296·6	− 38·0
2nd period, per cent. + or − 1st period	−25·3	−41·9	

Of hay, the average produce per acre per annum over the twenty years was: without manure, 2383lb.; with ammonia-salts alone, 2946lb.; with ammonia-salts and superphosphate (seventeen years), 3837lb.; with ammonia-salts and mixed mineral manure, with potash for six years, and without potash fourteen years, 5174lb.; and with ammonia-salts and the mixed mineral manure, including potash every year, 5711lb.

It is remarkable that there was, over the twenty years, almost identically the same amount of nitrogen taken up where the potash was discontinued as where it was continuously applied, and during the period of the omission there was even rather more. But of mineral matter, about one-fifth less has been taken off, over the fourteen years, in the crop grown without than with potash; and the falling off in amount, compared with the earlier period, is nearly 42 per cent. without, against only 25 per cent. with, the potash. Still, on plot 10 there was much less hay produced, and much less mineral matter taken up, than on plot 9, where the application of potash was continued.

It appears that, on plot 10, there was a considerable residue of potash remaining after the six years' application; that this was yielded up less freely than that from fresh supplies, but more freely in the earlier than in the later years; and that at the end of the fourteen years a residue still remained, of which some still continued to be yielded up. That this should be so is quite consistent with results obtained on arable land, which, as already referred to, show, both in the amounts of crop and in its chemical composition, the effects of a residue of potash applied more than twenty-five years previously. Supposing, however, that in the presence of an artificial supply of potash less was yielded up from the soil itself, the residue remaining would of course be by so much less than 200lb. at the end of the fourteen years.

About an equal number of species, and nearly the same species, were represented on plots 9 and 10, but on neither was the total number much more than half as many as without manure. On plot 9, receiving potash, the six grasses which have become most prominent are (somewhat in the following order) Poa pratensis, Agrostis vulgaris, Festuca ovina, Dactylis glomerata, Avena elatior, and Holcus lanatus, and they together average more than 80 per cent. of the produce. The seven most prominent grasses on plot 10, with the discontinued potash, are Festuca ovina, Agrostis vulgaris, Alopecurus pratensis, Avena elatior, Poa pratensis, Holcus lanatus, and Dactylis glomerata, which together make up about as much as the six on plot 9. The chief differences are that whilst Alopecurus has much increased on plot 10, there is scarcely any of it on plot 9; Holcus and Poa pratensis are the less prominent on plot 10; Dactylis glomerata has decreased on plot 10, but increased on plot 9; Festuca ovina has considerably increased on both plots, but the more on plot 10. Avena pubescens, Avena flavescens, Poa trivialis, Bromus mollis, and Lolium perenne have almost disappeared on both plots. Leguminous species represent only a small fraction of 1 per cent on both plots. Miscellaneous species have considerably decreased, more in weight than in number, on both plots.

On plot 9, with the continuous potash, the grasses showed much tendency to produce stem and seed, and to mature. On plot 10, with the potash discontinued, the proportion of leaf to stem was very much greater, the herbage was patchy, of a much darker green colour, and matured unevenly and imperfectly. There was, in fact, a relative plethora of nitrogen, and with the deficiency of potash a deficient assimilation of carbon.

Comparing the results on these plots with those on plots 7 and 8, where mixed mineral manure alone, with potash and without potash, was employed, it was noticed that on both the ammonia plots (9 and 10) the produce was chiefly gramineous, containing scarcely any leguminous herbage, and but few prominent miscellaneous species, whilst the flora was not very materially affected by the discontinuance of the potash; though, without the potash, the gramineous herbage showed very different, and much inferior, characters of development. Without ammonia, on the other hand, and with the potash, the produce contained a large proportion of leguminous herbage; and the most prominent effect of the discontinuance of the potash was the reduction of the leguminous herbage to a very insignificant amount, whilst, at the same time, the character of development of the grasses was deteriorated.

The importance of a liberal available supply of potash within the soil in order to grow large, properly developed, and well matured hay crops, is now made evident. With a fairly mixed herbage, and only moderate nitrogenous manuring, a liberal supply of potash will increase, or a deficiency of it will greatly diminish, the growth of leguminous plants; whilst, at the same time, both the quantity and the character of growth of the gramineous herbage will be affected. Or, with a predominantly gramineous herbage, and full supply of nitrogen, a deficient supply of potash will diminish the amount of produce and consequently the efficiency of the nitrogenous manure, and it will, moreover, lead to a deteriotion in the character of the growth.

14. *Mixed Mineral Manure alone* 7 *years; succeeding Ammonia-salts alone* 13 *years: Plot* 6.—The figures in Table XLIV. illustrate the effects of applying the mixed mineral manure, including potash, for seven years in succession on a plot which had received ammonia-salts, without mineral manure, in each of the thirteen preceding seasons (with sawdust in addition the first seven years). The comparisons are with plot 5, which received the same quantity of ammonia-salts (without sawdust) in each of the twenty years as was applied to plot 6 during the first thirteen years; and with plot 7, which received the same mixed mineral manure throughout the twenty years as plot 6 received during the last seven years.

The objects sought in discontinuing the application of ammonia-salts on plot 6, and substituting therefor the mixed mineral manure, were to determine the effects of the latter, not only on the amount of produce, but on the character of the herbage and of its chemical composition; and especially to acquire data in reference to the question whether any, or how much, of the nitrogen of the previous applications, which had not been already recovered in the increase of crop, would be so under the influence of liberal manuring.

TABLE XLIV.—AVERAGE PER ACRE PER ANNUM, BY MIXED MINERAL MANURE ALONE 7 YEARS, AFTER AMMONIA-SALTS ALONE 13 YEARS; PLOT 6.

	Average per Acre per Annum.				
	Plot 5. Ammonia-salts alone, 20 years.	Plot 6. Ammonia-salts, 13 years, Mineral Manure 7 years.	Plot 7. Mineral Manure alone, 20 years.	Plot 6. + or − Plot 5.	Plot 6 + or − Plot 7.
HAY.	lb.	lb.	lb.	lb.	lb.
1st period, 13 years, 1856-68 ...	3317	3425	3914	+ 108	− 489
2nd period, 7 years, 1869-75 ...	2257	3502	4040	+1245	− 538
Total period, 20 years, 1856-75	2946	3452	3958	+ 506	− 506
2nd period, per cent. + or − 1st period	−32·0	+ 2·2	+3·2		
NITROGEN.					
1st period	57·8	59·1	56·9	+ 1·3	+ 2·2
2nd period	43·0	41·9	55·9	− 1·1	−14·0
Total period	52·6	53·1	56·6	+ 0·5	− 3·5
2nd period, per cent. + or − 1st period	−25·6	−29·1	−1·8		
MINERAL MATTER (ASH).					
1st period	171·8	175·6	254·5	+ 3·8	−78·9
2nd period	95·4	189·2	252·8	+ 93·8	−63·6
Total period	145·1	180·4	254·0	+ 35·3	−73·6
2nd period, per cent. + or − 1st period	−44·5	+ 7·7	−0·7		

A consideration of the facts shows it is probable that, after the thirteen years' application of ammonia-salts to plot 6, some, at any rate, of the supplied nitrogen remained within the soil, and that some of this was available to the growing plants during the succeeding seven years. Moreover, a glance at the table will show that as much nitrogen was taken up as on the plot where the ammonia-salts were still annually applied; but in reference to this point there is the significant fact that the surface soil of plot 6 showed at the end of twenty years a notably lower percentage of nitrogen than the corresponding layer of plot 5, thus pointing to the soil itself as being the source of nitrogen. The reader may here find it instructive to refer back to the discussion of the results on plot 7, page 149.

Since the application of the mixed mineral manure, the flora of plot 6 has become much more complex. Agrostis vulgaris and Festuca ovina are less predominant, Holcus lanatus has much increased, whilst Dactylis glomerata, Avena elatior, Avena pubescens, Lolium perenne, and Poa pratensis are more favoured than on plot 5. Of leguminous plants, the creeping and comparatively surface-rooting Lathyrus pratensis has much increased, as has the leguminous herbage as a whole. With its increasing complexity, the roots of the herbage would doubtless acquire possession of a more extended range of soil and subsoil, and more varied powers of underground food-collection would come into play. Whilst, therefore, some part of the nitrogen of the increased produce obtained on the substitution of the mineral for the nitrogenous manuring would probably be derived from the residue of the previous applications, it is probable that the greater part would be due to increased power of underground food collection, by virtue of which not only the immediately preceding, but the earlier accumulations, or what may be termed the normal stores of the soil and subsoil, would be drawn upon. That such was really the case is concluded from the fact of the reduction of the percentage of nitrogen in the surface soil of plot 6, as of plot 7, where mineral manure alone had been applied for twenty years, and where the very complex and highly leguminous herbage accumulated throughout the period an otherwise unaccountably large amount of nitrogen.

There was, over the seven years, more of every mineral constituent (except soda) taken up on plot 6 with the mineral manure than on plot 5 with the ammonia-salts. Of potash there was nearly four times, of phosphoric acid about two and a half times, of sulphuric acid about one and a half times, and of silica (of which there was none in the manure) more than one and a half times, as much taken up as where the ammonia-salts were still used. There was, however, less of every mineral constituent (except soda) taken up than where the mixed mineral manure had been applied from the commencement (plot 7).

It is obvious that it was of potash chiefly, of phosphoric acid also notably, but of most of the mineral constituents more or less, that the available supply had become so deficient under the continuous application of the ammonia-salts. It has already been shown how ineffective was a supply of phosphoric acid (superphosphate) when used alone (plot 4—I.), and how comparatively little was its effect when used in conjunction with ammonia-salts, but without potash (plot 4*b*); and here again is strikingly brought out the influence of a liberal available supply of potash within the soil, both upon the quantity and the quality of the produce. Lastly, such evidence as is forthcoming does not favour the supposition that any considerable proportion of the nitrogen of the ammonia-salts applied during the thirteen years, and not recovered in the crops during the period of the application, remained in an available condition in the soil, and was reclaimed in the succeeding seven years under the influence of the mixed mineral manure.

15. *Equal Nitrogen and equal Potash, in Nitrate of Soda and Sulphate of Potash, and in Nitrate of Potash; in each case with Superphosphate of Lime: Plots* 19 *and* 20.—The marked effects of nitrate of soda and of sulphate of potash pointed to the desirability of determining whether

nitrate of potash would be more or less effective than a mixture of nitrate of soda and sulphate of potash, the mixture containing the same amounts of nitrogen and potash as the nitrate of potash. In 1872, plots 19 and 20 were set apart for this test. In each of the seven years, 1872-78 (and the experiment is still in progress), plot 19 received 275lb. nitrate of soda, and plot 20 327lb. nitrate of potash, both containing the same weight of nitrogen. Plot 19 also received 290lb. sulphate of potash, containing the same weight of potash as the 327lb. nitrate of potash. Each plot has also received annually 3½ cwt. superphosphate of lime. For comparison there is given in Table XLV. the average produce over the same seven years, and also over the preceding fourteen years, on plot 16, manured annually, during the whole period of twenty-one years, with 275lb. nitrate of soda, 300lb. sulphate of potash, 100lb. sulphate of soda, 100lb. sulphate of magnesia, and 3½ cwt. superphosphate of lime. The quantities of manures on each plot are not repeated in the table.

TABLE XLV.—AVERAGE PER ACRE PER ANNUM, BY NITRATE OF SODA AND SULPHATE OF POTASH, AND BY NITRATE OF POTASH, CONTAINING EQUAL NITROGEN AND EQUAL POTASH, IN EACH CASE WITH SUPERPHOSPHATE; PLOTS 19 AND 20.

		Per Acre per Annum.		
		Plot 16.	Plot 19.	Plot 20.
	HAY.	lb.	lb.	lb.
14 years, 1858-71	One crop only each year	5451	—	—
7 years, 1872-78	First crop only each year	4716	4368	4362
7 years, 1872-78	Including second crops, 1875-77-78	5639	5273	5191
	NITROGEN.			
14 years		66·1	—	—
7 years		54·0	49·1	47·9
		69·0	62·5	61·1
	MINERAL MATTER (ASH).			
14 years		331·4	—	—
7 years		283·8	261·4	254·4
		369·9	336·4	322·6

Plot 16 received rather more potash, and more soda, magnesia, and sulphuric acid, than plot 19; and plot 20, with the same amount of nitrogen and potash as plot 19, received no soda, and less sulphuric acid, but the nitric acid and the potash were applied to the soil in combination.

Each plot has maintained a fairly mixed herbage. With only a moderate supply of nitrogen, and this in the form of nitrate, and with a liberal supply of potash, leguminous herbage increased on all three, this increase being mainly due to Lathyrus pratensis, but partly, on plots 19 and 20, to Trifolium repens also. On all three plots the bulk of the gramineous herbage is made up of a good many species; and on plot 16, which has been the longest under treatment, the mixture is greater—that is, there is less predominance of individual species; Festuca ovina, Agrostis vulgaris, Alopecurus pratensis, Avena flavescens, and Holcus lanatus are somewhat equally represented, whilst Poa trivialis, Dactylis glomerata, and Lolium perenne each show moderate growth. On plots 19 and 20 Festuca ovina is more prominent, and Holcus lanatus is increasing; Agrostis vulgaris, though abundant, is decreasing; whilst Alopecurus pratensis, Avena flavescens, Avena pubescens, and Poa trivialis are each fairly represented and increasing. There is, on all three plots, a pretty normal character of growth, fair proportion of stem, and tendency to maturation of the grasses.

The yields of dry matter, of nitrogen, and of mineral matter indicate greater maturation or ripeness on plot 20 with the nitrate of potash, than on plot 19 with the nitrate of soda and sulphate of potash.

Analyses of the ash of the first crops for the seven years, and of the second crops for the three years, show that the produce of plot 16, with the fuller mineral manure and longer continuance of the experiment, contained, both per acre and per cent. in its dry substance, more phosphoric acid, considerably more potash, and rather more magnesia, than that of either plot 19 or 20. But it contained less lime than that of either of the other plots, and less soda and chlorine than that of plot 19; whilst that of plot 20, with nitrate of potash, but without soda in the manure, contained very much less soda than that of either plot 16 or plot 19 with it. The produce of plot 20 contained less sulphuric acid, chlorine, and silica, than that of plot 19, but more lime, and especially more potash, both per acre and per cent.

The conclusion is that there is no marked difference in the amount, or in the botanical composition, of the produce, whether the nitrogen and the potash be supplied as nitrate of soda and sulphate of potash, or as nitrate of potash; but the data at command as to the chemical composition would indicate a somewhat more matured condition of the produce grown by the nitrate of potash.

The great practical value of the Rothamsted experiments is very well illustrated in the two cases now to be brought under notice. They deal, on the one hand, with the effects upon the herbage of permanent meadow produced by the application of a mixture containing the ash-constituents, and the nitrogen, removed by the crop; and, on the other hand, with the results obtained after the application of farmyard manure. In the one case the results serve to demonstrate the fallacy of a weighty proposition first enunciated by Liebig, and, in the second case, they throw much light upon the solution of that important question—the fate of the nitrogen of the soil.

16. *Mixture supplying the Ash-constituents, and the Nitrogen, of* 1 *ton of Hay: Plot* 18.—This is the last of the series of experiments with artificial and chemical manuring substances. Commencing in 1865, this plot has annually received a mixture containing the quantities of potash, soda, lime, magnesia, phosphoric acid, silica, and nitrogen, contained in 1 ton of hay, and it also supplied sulphuric acid and chlorine in abundance. The object in view was, in part, to put to the test of direct experiment the principles of manuring set forth

by Liebig, according to which *all the constituents*, neither more nor less, removed in crops, should be returned to the soil. Liebig wrote, in his "Principles of Agricultural Chemistry:" "Our first object will naturally be, to restore to the soil the mineral constituents in the same quantity and in the same proportions as those in which they have been removed in the crops; and *none must be omitted.*" Another object of this experiment was to acquire data as to the proportion in which the several constituents artificially supplied would be removed in the increase of crop.

The manures actually applied, and the constituents they contained, were as follows:

76lb. commercial chloride of potassium	38·0lb. potash 7·0lb. soda 36·7lb. chlorine
35lb. sulphate of magnesia	5·6lb. magnesia 11·1lb. sulphuric acid
26lb. bone ash	11·0lb. lime 8·2lb. phosphoric acid
26lb. sulphuric acid (sp. gr. 1·7)	16·9lb. sulphuric acid
50lb. silicate of soda	?lb. soda 23·0lb. soluble silica
50lb. silicate of lime.......................	?lb. lime 8·0lb. soluble silica
164lb. "ammonia-salts"......	30·1lb. nitrogen 44·4lb. sulphuric acid 46·2lb. chlorine

If the quantity of constituents as shown in the right-hand column be compared with the contents of 1½ tons of hay as given previously in Table XXIX., page 142, it will be seen that fully sufficient of each constituent has been supplied for an increase of 1 ton of hay, whilst of soda, sulphuric acid, and chlorine there is more than sufficient.

The experiment was carried on for eleven years, and in Table XLVI., page 186, comparison is made with the results on the unmanured plot during the same eleven years.

It may be seen that the average yield of hay over the first half of the period was about 35cwt., and over the second half rather less than 30cwt.; whereas over the whole period it was rather more than 32cwt. Hence there was a reduction in the total produce during the later years. But, in order to estimate the effects of the manure, it is necessary to deduct something for the annual yield of the soil and seasons; and, as plot 18 had, like plot 3, been unmanured from the commencement of the trials in 1856, it will be fair to deduct from the total amount that obtained on the unmanured plot. The differences, given in the right-hand column, show an average annual increase of produce, due to the manure, of not quite $12\frac{1}{2}$cwt. during the first period, about $13\frac{1}{2}$cwt. during the second, and not quite 13cwt. over the whole

TABLE XLVI.—AVERAGE PER ACRE PER ANNUM, BY A MIXTURE SUPPLYING THE ASH CONSTITUENTS, AND THE NITROGEN, OF 1 TON OF HAY; PLOT 18.

	Average per Acre per Annum.		
	Plot 3. Without manure.	Plot 18. Nitrogen and ash constituents of 1 ton of hay.	Plot 18. + or − Plot 3.
HAY.	lb.	lb.	lb.
1st period, 5½ years	2514	3908	+1394
2nd period, 5½ years	1787	3301	+1514
Total period, 11 years, 1865-75 ...	2151	3604	+1453
2nd period, per cent. + or − 1st period	−28·9	−15·5	
NITROGEN.			
1st period	35·1	50·1	+ 15·0
2nd period	24·3	39·9	+ 15·6
Total period	29·7	45·0	+ 15·3
2nd period, per cent. + or − 1st period	−30·8	−20·4	
MINERAL MATTER (ASH).			
1st period	146·7	222·7	+ 76·0
2nd period	96·9	175·7	+ 78·8
Total period	121·8	199·2	+ 77·4
2nd period, per cent. + or − 1st period	−33·9	−21·1	

period. The increased amount of nitrogen in the produce is only about 45 per cent. of that supplied; and the increase of mineral matter removed is not much more than half as much as would be contained in 1 ton of hay.

It is clear, then, that the annual supply of not only the mineral constituents, but the nitrogen also, of 1 ton of hay, yielded less than two-thirds instead of 1 ton of increase of produce; moreover, the character of the herbage was materially modified. The gramineous herbage was much increased, the leguminous much reduced.

The chief interest of this plot lies, perhaps, in the circumstance of its putting to the test the principle enunciated by Liebig, and quoted above. Liebig, in his earlier writings, did not recognise the fact that a considerable proportion of the constituents removed from the land in crops is, in the actual practice of agriculture, periodically returned to it, and that, therefore, the loss to the soil is not measured by the amount of constituents in the crops grown, but more nearly by that in the produce sold off the farm. Further, his recommendations for the carrying out of his principle were confined to the application of the "mineral" or *ash-constituents*; he maintaining that the atmosphere would supply the necessary nitrogen. It is true that, subsequently, in the course of controversy, he changed the meaning of his terms, and then included ammonia-salts in the category of mineral manures. It is seen, however, that even with a supply of the amount of nitrogen, as well as ash-constituents, contained in 1 ton of hay, not two-thirds of a ton of increase of produce was obtained.

With regard to the applicability of Liebig's principle, certain considerations must not be overlooked First, there is no conceivable condition of chemical combination, and of distribution within the soil, in which the various constituents could be annually supplied so as to be all annually taken up by growing vegetation; and there is conclusive evidence that, in some cases, the unrecovered residue is, in greater or less part, lost by drainage; and that, so far as it is not so, it becomes so locked up, or distributed within the soil, that it is—at any rate very slowly, and, in some cases, perhaps never fully—recovered in subsequent crops.

Secondly, the principle ignores the difference in the character and capabilities of different soils. Take two opposite cases: A light, porous, almost exclusively sandy soil, which itself yields up little or nothing to growing plants, but which may, nevertheless, produce good crops under high farming, will probably suffer great loss of manurial constituents by natural drainage; so that, if no more were to be supplied than were removed, there must obviously be a decline of fertility. Suppose, on the other hand, a rich and deep loam, which would, under good mechanical cultivation and drainage, supply annually a considerable amount of potash, for example, to say nothing of other constituents, for hundreds and perhaps for thousands of years; surely, in such a case, it is not necessary to supply as much in manure as has been removed in the crops.

Further, experience teaches that, in the actual condition of our soils, and of agricultural practice, the exact composition of the crops we remove, or wish to grow, is no direct guide to the description and the amount of manurial constituents which will be most effective. Thus, an average crop of wheat will remove even rather more phosphoric acid than an average crop of barley; but experience teaches that, in the case of land of the same description, and in the same condition, superphosphate of lime is, as a rule, used with very much more benefit to the spring-sown barley than to the autumn-sown wheat. The wheat, being put in four or five months earlier, has so much more time for root-distribution, and acquires a greater capability for food collection. The barley, on the other hand, depends very much more upon the stores available within the surface soil. Again, superphosphate is, in practice, of very special benefit to the so-called "root crops," though the amount of phosphoric acid they take up, compared with other crops, would not indicate this. Then, turning from the mineral or ash-constituents to the nitrogen, an average crop of beans will contain from two to three, and one of clover-hay from three to four, or more, times as much nitrogen as one of wheat or barley; but land in such condition as to grow a full crop of the rich-in-nitrogen beans or clover, without nitrogenous manure, would not grow a full crop of wheat or barley, containing so much less nitrogen, without liberal nitrogenous manuring.

It is, then, under the existing conditions of practical agriculture, certainly not necessary to supply to the land all the constituents that have been removed from it, or that would be contained in the crops it is wished to grow, and neither more nor less of them than would be so removed. On the contrary, we should supply all, or only some, and more or less, according to the circumstances.

17. *Farmyard Manure alone, and with Ammonia-salts in addition: Plots* 2 *and* 1.—The effects of various important individual constituents of manures, and of various mixtures of them, having been discussed, it now remains to interpret the results obtained on the application of that complex and heterogeneous mixture, farmyard manure.

For eight years, 1856-63, plot 2 received annually farmyard manure at the rate of 14 tons per acre. Over the same period, plot 1 received the same quantities of farmyard manure, but with 200lb. ammonia-salts per acre per annum in addition. At the end of the eight years the application of farmyard manure was stopped on both plots, but the ammonia-salts were still annually applied to plot 1. The reason the farmyard manure was withheld was partly because so large an annual application was obviously not thoroughly taken up by the soil, and it was thought somewhat obstructed the vegetation; and partly because calculation indicated how small a proportion of the constituents applied was recovered in the increase of crop, and that there was, therefore, a considerable accumulated residue, the amount and the duration of the effects of which it would be of interest to trace.

TABLE XLVII.—AVERAGE PER ACRE PER ANNUM, BY FARMYARD MANURE ALONE, AND WITH AMMONIA-SALTS; AND BY THE RESIDUE OF THE DUNG, ALSO WITHOUT AND WITH AMMONIA-SALTS: PLOTS 2 AND 1.

	Average per Acre per Annum.					
	Plot 3. Unmanured continously.	Plot 2. As stated above.	Plot 1. As stated above.	Plot 2. + or – Unmanured.	Plot 1. + or – Unmanured.	Plot 1. + or – Plot 2.
HAY.	lb.	b.	lb.	lb.	lb.	lb.
1st period, 8 years, 1856-63	2665	4804	5538	+ 2139	+ 2873	+ 734
2nd period, 6 years, 1864-69	2699	4846	5366	+ 2147	+ 2667	+ 520
3rd period, 6 years, 1870-75	1692	2517	3331	+ 825	+ 1639	+ 814
Total period, 20 years, 1856-75	2383	4130	4824	+ 1747	+ 2441	+ 694
2nd period, per cent. + or – 1st period	+ 1·3	+ 0·9	– 3·1			
3rd period, per cent. + or – 1st period	–36·5	–47·6	–39·9			
NITROGEN.						
1st period	37·2	58·2	68·3	+ 21·0	+ 31·1	+10·1
2nd period....................	37·3	53·3	63·9	+ 16·0	+ 26·6	+10·6
3rd period	23·0	27·5	41·0	+ 4·5	+ 18·0	+13·5
Total period	33·0	47·5	58·8	+ 14·5	+ 25·8	+11·3
2nd period, per cent. + or – 1st period	+ 0·3	– 8·4	– 6·4			
3rd period, per cent. + or – 1st period	–38·2	–52·7	–40·0			
MINERAL MATTER (ASH).						
1st period	160·5	329·1	370·5	+168·6	+210·0	+41·4
2nd period....................	152·2	275·0	291·8	+122·8	+139·6	+16·8
3rd period	91·5	136·4	164·7	+ 44·9	+ 73·2	+28·3
Total period	137·3	255·0	285·1	+117·7	+147·8	+30·1
2nd period, per cent. + or – 1st period	– 5·2	–16·4	–21·2			
3rd period, per cent. + or – 1st period	–43·0	–58·6	–55·5			

In Table XLVII. the comparisons are made with the unmanured plot 3. It has already been intimated that plot 2 received farmyard manure alone for eight years, 1856-63, and then remained unmanured for twelve years, 1864-75; whilst plot 1 received farmyard manure and ammonia-salts for eight years, 1856-63, and ammonia-salts only for twelve years, 1864-75.

It is remarkable that, over the first six years of the cessation of the application of the manure, the average produce was almost exactly the same as, and even rather more than, during the application—4846lb. against 4804lb.; and the average annual increase was almost identical—2147lb. against 2139lb. Though one or two of the six years were very productive seasons, the result is still very striking. The next six years were rather the reverse in this respect, and this, with the fact that the then remaining residue would doubtless be in a less readily available condition, led to there being little more than half as much average produce, and less than two-fifths as much average increase, as over the first six years of the action of the manurial residue.

The figures show that very much more nitrogen was removed in the crops during the first than during the second six years of the action of the residue. Moreover, the amount of nitrogen taken up per acre per annum over the first six years was less than during the eight years of manuring. The reverse was the case with the yield of hay.

Of mineral matter, there was twice as much removed in the first as in the second six years of the action of the residue; and there was of it a greater falling off in the first six years, compared with the years of the application, than of either the hay or the nitrogen.

The effect of the farmyard manure was to reduce the number of species, to bring into greater prominence the gramineous and miscellaneous herbage, but to reduce the leguminous. The gramineous species became fewer. Poa trivialis, Bromus mollis, and Avena flavescens were the most prominent, whereas, without manure, not one of these made much show, Festuca ovina, Agrostis vulgaris, Avena pubescens, and Holcus lanatus being then the leading grasses. After the supply of farmyard manure ceased, however, the same grasses as without manure gradually became more prominent on plot 2, whilst the Poa trivialis and Bromus mollis had, in 1877, become insignificant in quantity. It may be stated generally that, in the later years, there was on plot 2, as compared with plot 3, a higher percentage and a considerably larger quantity per acre of gramineous herbage; a considerably lower percentage and a smaller amount per acre of leguminous herbage; and a rather lower percentage, but a somewhat larger actual amount, of miscellaneous herbage.

As the grasses increased, and the leguminous plants diminished, under the farmyard manure, the herbage contained a considerably lower and decreasing percentage of nitrogen; but there was a higher percentage of total mineral matter. Of lime, magnesia, soda, and sulphuric acid there was more, and of potash, phosphoric acid, chlorine, and silica very much more, removed per acre from the farmyard manured than from the continuously unmanured plot. There was a greater or less available residue of all the mineral constituents, and more especially of potash, phosphoric acid, and silica, many years after the cessation of the application of the manure.

At what rate, and in what proportion, have the several constituents of the farmyard manure, which were not recovered during the years of the application, been recovered since, and what prospect is there of their final total recovery?

To answer this question there is on the one hand, a tolerably correct estimate of the amounts of nitrogen, and of the several mineral constituents, removed in the crops during the separate periods, but it is a more difficult matter to arrive at the amount of the same constituents contained in the 112 tons of farmyard manure applied per acre to the plot during the eight years. The following figures, however, are based on the best available data. Of nitrogen it is estimated that the farmyard manure will, on the average, contain 0·64 per cent., and, therefore, that 200·7lb. were applied per acre per annum ; or, in all, 1606lb. in the eight years. During the eight years the produce removed about 29 per cent. as much nitrogen as is thus estimated to be supplied in the manure ; during the next six years about 20 per cent. ; and during the last six of the twenty years about 10 per cent. more was removed, making a total of about 59 per cent. as much removed in the whole produce of the twenty years as had been supplied during the eight years. But it must not be assumed that the whole of the nitrogen of the crops came from the manure. It would be more correct to deduct the amount obtained in the unmanured produce, and to regard only the so-reckoned increase as due to the manure. Estimated thus, only 10·4 per cent. of the supplied nitrogen was recovered as increased yield during the eight years of the application; only 6 per cent. more during the next six years; and only 1·7 per cent. during the second six years since the application ; making, in all, a recovery as increase during the twenty years of about 18·1 per cent. of that supplied in the first eight years.

Thus, on the supposition that the whole of the nitrogen of the produce was derived from the manure, there would still remain, at the end of the twenty years, about 41 per cent. of the 1606lb., or about 658lb., not accounted for. But, on the supposition that only the increase above that in the unmanured produce was derived from the manure, which is, doubtless, at any rate much nearer the truth, there would remain unaccounted for, at the end of the twenty years, 81·9 per cent. of the nitrogen supplied—that is, about 1315lb.; and yet, during the last six years of the twenty, less than 2 per cent. of the original amount supplied was recovered as increase. The prospect of recovering the whole, or even a considerable proportion would thus seem, to say the least, extremely remote.

FATE OF THE NITROGEN IN THE SOIL.

It has already been shown what large quantities of nitrogen were supplied to the farmyard manure plots in the experiments upon permanent meadow land, and how little became recovered in the crop. Does this large amount of unrecovered supplied nitrogen remain in the soil, and in such a condition of combination and distribution as to be available to succeeding crops? Or may not some of it be lost by drainage, or in other ways, and the remainder become so locked up or distributed as to be so slowly recoverable, if ever, that it can be reckoned of scarcely appreciable practical value?

TABLE XLVIII.—ESTIMATED AMOUNT OF DRY SOIL PER ACRE AT EACH DEPTH; NITROGEN PER CENT. IN THE DRY SOILS, AND ESTIMATED NITROGEN PER ACRE, AT EACH DEPTH.

	Average Dry Soil per Acre, exclusive of Stones.	Nitrogen.				
		Per cent. in Dry Soil.		Per Acre.		
		Plot 3. Unmanured.	Plot 2. Farmyard manure 8 yrs., no manure 12 yrs.	Plot 3. Unmanured.	Plot 2. Farmyard manure 8 yrs., no manure 12 yrs.	Plot 2. + or − Plot 3.
	lb.	Per cent.	Per cent.	lb.	lb.	lb.
1st depth, 1-9in. ...	2,183,375	0·2565	0·2800	5600	6113	+513
2nd depth, 10-18in.	2,835,339	0·0724	0·0849	2053	2407	+354
3rd depth, 19-27in.	2,964,176	0·0458	0·0473	1358	1402	+ 44
4th depth, 28-36in.	3,049,436	0·0425	0·0402	1296	1226	− 70
5th depth, 37-45in.	3,104,583	0·0381	0·0337	1183	1046	−137
6th depth, 46-54in.	3,080,909	0·0376	0·0319	1158	983	−175
Total, 27in. ...	7,982,890	—	—	9011	9922	+911
Total, 54in. ...	17,217,818	—	—	12,648	13,177	+529

Samples of the soils of all the experimental grass plots were taken in February and March, 1876, that is, after the experiments had been in progress twenty years, and before the next growing season had commenced. Table XLVIII. shows, for plot 3 (unmanured) and plot 2 (farmyard manure eight years, unmanured twelve years) :

1. The calculated average amounts of soil, free from stones, and free from moisture expelled at 100° C., in pounds per acre, for each layer of 9in. down to a depth of 54in. ;
2. The percentage of nitrogen in the dry mould of each 9in. layer, as determined by the soda-lime method ;
3. The calculated nitrogen per acre in pounds ;
4. The difference in amount between the two plots.

The foregoing results as to the accumulation of the nitrogen of the manure within the soil, adopted on the basis of the determinations to the total depth of 54 inches, may be discussed in connection with the figures given below in Table XLIX.

TABLE XLIX.—ESTIMATED NITROGEN SUPPLIED IN THE MANURE, RECOVERED IN THE INCREASE OF THE HAY CROP, DETERMINED AS RESIDUE IN THE SOIL, AND NOT RECOVERED IN EITHER THE INCREASE OR THE SOIL, TO THE DEPTH OF 54 INCHES.

	Nitrogen of Manure.	
	Per Acre.	Per Cent.
	lb.	
Supplied in farmyard manure in 8 years	1606	—
Recovered in increase in 20 years (over Plot 3)	291	18·1
Not recovered in increase......................	1315	81·9
Residue, determined by soda-lime, in soil 54in. deep	529	32·9
Not recovered in increase or in soil	786	49·0

In interpreting these figures it is necessary to bear in mind the uncertainty in the estimate of the amount of nitrogen supplied in the manure; the difficulty in determining how much of the nitrogen of the produce was derived from that supplied; the possible natural difference, apart from the influence of manure, in the soils and subsoils of the respective plots; and also the unavoidable range of error in the sampling of, and determinations of nitrogen in, the soils, and the calculation of such data into quantities per acre. Taking into account the figures relating to the first, second, and third depths only—that is, only so far as the manured soil shows more nitrogen than the unmanured—the result as to accumulation and loss of nitrogen will stand as shown in Table L.

TABLE L.—ESTIMATED NITROGEN SUPPLIED IN THE MANURE, RECOVERED IN THE INCREASE OF THE HAY CROP, DETERMINED AS RESIDUE IN THE SOIL, AND NOT RECOVERED IN EITHER INCREASE OR SOIL, TO THE DEPTH OF 27 INCHES.

	Nitrogen of Manure.	
	Per Acre.	Per Cent.
	lb.	
Supplied in farmyard manure in 8 years	1606	—
Recovered in increase in 20 years (over Plot 3)	291	18·1
Not recovered in increase......................	1315	81·9
Residue, determined by soda-lime, in soil 27in. deep	911	56·7
Not recovered in increase or in soil	404	25·2

It is then practically beyond doubt that only a comparatively small proportion of the nitrogen supplied in the farmyard manure was recovered in the increase of crop; that there was a considerable accumulation of it within the soil; and that there was also a very considerable amount so far unaccounted for.

Such a result would seem to require some confirmation, and this is not wanting. The great practical importance of the subject now under discussion renders it desirable to notice somewhat fully this confirmatory evidence. Among the experiments at Rothamsted, wheat has been grown year after year on the same land from 1843-4 up to the present time, and barley in like manner from 1852 up to the present time. In the case of each crop, one plot has received 14 tons of farmyard manure per acre per annum, and another a mixed mineral manure, without nitrogen, every year. The results shown in Table LI. were obtained from these plots.

TABLE LI.—NITROGEN SUPPLIED IN FARMYARD MANURE, RECOVERED, AND NOT RECOVERED, IN THE INCREASE OF PRODUCE OF WHEAT AND OF BARLEY.

	Nitrogen per Acre per Annum.				For 100 Nitrogen in Farmyard Manure.	
	Supplied in Farmyard Manure.	In Produce by Mineral Manure.	In Produce by Farmyard Manure.	In Increase by Farmyard Manure.	Recovered in Increase.	Not Recovered in Increase.
	lb.	lb.	lb.	lb.	Per cent.	Per cent.
Wheat, 20 yrs., 1852-71	200·7	20·1	49·3	29·2	14·6	85·4
Barley, 20 yrs., 1852-71	200·7	23·9	45·3	21·4	10·7	89·3

It will be seen that the figures in the fourth column are got by deducting those in the second from those in the third.

After making allowance for certain variations in the method and duration of the experiments with wheat and barley, on the one hand, and with the meadow herbage on the other, the general result is that, according to the estimates, a higher proportion of the supplied nitrogen was annually recovered over the twenty years in the autumn-manured and autumn-sown (and so longer grown) wheat, than in the spring-manured and spring-sown barley; and that about the same proportion was recovered in the barley as over the eight years in the grass. Obviously the estimate of the nitrogen in the increase is likely to be nearer the truth in the case of the two cereal crops than in that of the mixed herbage, the character of which, and consequently the capability of collection from normal sources, is so changed by manure. Any way, neither with the wheat, the barley, nor the mixed herbage, was there more than from 10 to 15 per cent. of the nitrogen, supplied in the farmyard manure, recovered in the increase of crop during the years of application.

In the case of the barley experiments, after the farmyard manure had been applied for twenty years in succession, the plot was divided. To one-half the dung was still annually applied, but the other was now left without any further manure. The result as to the recovery of the nitrogen of the manure in the two cases is recorded in a table which is not reproduced here. The figures indicate, however, that over the twenty years of the application (on the whole plot) 10·7 per cent. of the supplied nitrogen is so estimated to be recovered in the increase of the crop; over the next six years of the continued application, on half the plot, 15·7 per cent; and over the total period of twenty-six years 11·8 per cent. On the other half there was the 10·7 per cent. of the twenty years' supply recovered during the twenty years, 2·9 per cent. more of it during the next six years, and in all 13·6 per cent. of the twenty years' supply recovered in the twenty-six years. That is to say, of 4014lb. of nitrogen estimated to be supplied in the twenty years, 86·4 per cent., or 3468lb., remained unaccounted for in the increase of crop at the end of the twenty-six years.

As only 2·9 per cent. of the original supply of nitrogen was recovered in the first six years after the application of the manure ceased, or, say, 0·5 per cent. per annum, it would obviously take from one hundred and seventy to one hundred and eighty years to recover the whole of the 89·3 per cent. (=100—10·7) which remained, if at the same rate as during the first six years. There can be little doubt, however, that part of the unrecovered amount has been lost by drainage or otherwise, and that, whatever residue remains, a gradually decreasing proportion of it will be annually recovered.

With regard to the wheat plots, samples of the soils have been taken, and their nitrogen estimated, with the view of determining whether or not the whole of the unrecovered nitrogen of the farmyard manure remains available within the soil.

In the autumn of 1865, after twenty-two years' continuous growth of wheat, samples of the soils were taken from many of the plots, in each case from the first 9in., the second 9in., and the third 9in. in depth. Rather more than one and two-thirds as much nitrogen was determined in the first 9in. of the farmyard-manured as in the corresponding layer of the unmanured plot, and about one and a half times as much as to a corresponding depth of any of the plots receiving artificial nitrogenous manures. Determinations made after the farmyard manure had been applied some years longer showed more than twice as much nitrogen in the first 9in. as without manure. Table LII. is drawn out in the same form as Table XLVIII., page 194.

TABLE LII.—EXPERIMENTAL WHEAT FIELD.—ESTIMATED AMOUNT OF DRY SOIL PER ACRE AT EACH DEPTH; NITROGEN PER CENT. IN THE DRY SOILS, AND ESTIMATED NITROGEN PER ACRE, AT EACH DEPTH.

	Average Dry Soil per Acre, exclusive of Stones.	Nitrogen.				
		Per cent. in Dry Soil.		Per Acre.		
		Plot 3. Unmanured.	Plot 2. Farmyard Manure.	Plot 3. Unmanured.	Plot 2. Farmyard Manure.	Manured + or − Unmanured.
	lb.	lb.	Per cent.	lb.	lb.	lb.
1st depth, 1-9in. ...	2,287,155	0·1090	0·1882	2493	4304	+1811
2nd depth, 10-18in.	2,712,508	0·0738	0·0810	2002	2197	+ 195
3rd depth, 19-27in.	2,848,973	0·0561	0·0619	1598	1764	+ 166
Total, 27in. ...	7,848,636	—	—	6093	8265	+2172

Furthermore, in the case of the wheat experiments, as shown in Table LIII., page 200, the loss of nitrogen by drainage or otherwise is estimated to be about 40 per cent. of that supplied; in that of the hay plot reckoned to the same, or 27in., of depth (Table L., page 196), 25·2 per cent., or, to the depth of 54in. (Table XLIX., page 195), 49 per cent.

It is now clear that only a comparatively small proportion of the nitrogen supplied in farmyard manure is recovered in the increase of crop. The residue actually determined in the soil is very large; and it is possible that the whole of the nitrogen existing as nitric acid, especially in the subsoil, is not accounted for by the soda-lime determinations. It is very remarkable, however, that, notwithstanding this great ascertained accumulation, and the annually renewed supply by manure, larger quantities of corn, or of straw, or of both, and also of hay, are every year obtained by the use (in conjunction with mineral manures) of much less than half as much nitrogen applied as ammonia-salts or as nitrate of soda. The wheat plots so manured, and so yielding, at the same time show less than two-thirds as high a percentage of nitrogen in the first 9 inches of depth.

Table LIII. — Experiments on Wheat. — Estimated Nitrogen supplied in the Manure, recovered in the increase of Crop, determined as Residue in the Soil, and not recovered in either the Increase or the Soil, to the depth of 27 inches.

	Nitrogen of Manure.	
	Per Acre.	Per Cent.
	lb.	—
Supplied in farmyard manure in twenty-two years	4415	
Recovered as increase of crops	470	10·7
Not recovered in increase........................	3945	89·3
Residue determined by soda-lime in soil 27in. deep	2172	49·2
Not recovered in increase or in soil	1773	40·1

But, according to the estimates, besides the actually-determined large residue within the soil, there was also in each case a very large amount of nitrogen unaccounted for, either in the increase of crop or in the soil, to the depths examined. Direct experiments have shown that the soil in the wheat field, which is manured annually with farmyard manure, retains near the surface, owing to its greatly increased porosity, very much more of the rainfall than the soil of the plots not so manured. Accordingly the drain from the farmyard-manured plot runs much less frequently than do the drains from the unmanured or the artificially-manured plots. There will, obviously, be less loss of water by drainage. But it is found that a given volume of the drainage water from the farmyard-manured plot contains from two to three or more times as much nitrogen, in the form of nitrates and nitrites, as that from the unmanured plot, or from the plots with mineral without artificial nitrogenous manure. Here, then, is a determined source of loss of the supplied nitrogen. A considerable further loss is probably due to decomposition of the nitrogenous organic matter within the soil and evolution as free nitrogen.

Consequently, there is cumulative evidence to show that the nitrogen supplied as farmyard manure was recovered in very small proportion during the years of its application; that in after years it was recovered in constantly decreasing proportion; that there, nevertheless, remained a considerable, but very slowly available, residue; that there was a considerable loss by drainage; and, finally, that there is probably a further loss by decomposition, and evolution into the atmosphere.

It is well, however, to remember that in ordinary agriculture much less farmyard manure would be applied than in these special experiments, and the losses by drainage would from that cause alone be proportionately less. Much, obviously, would also depend on the character of the soil and the subsoil. Again, in an ordinary rotation of various crops, more of the supplied nitrogen would probably be gathered up before it finally passed beyond the reach of vegetation, than in the case of a single cereal crop grown year after year on the same land. For somewhat similar reasons a better result might have been looked for with the mixed herbage, as compared with the cereal crops, than the evidence would appear to show. That it was not so may perhaps be taken to indicate that, in estimating the proportion of the nitrogen of the produce due to that supplied in the manure, it should not be assumed that as much was derived from natural sources as in the case of the unmanured produce; but more should be reckoned as derived from the manure.

FATE OF THE FERTILISING MINERALS IN THE SOIL.

Having thus somewhat fully discussed the fate of the nitrogen of farmyard manure, it remains to glance ever so briefly at the behaviour of the mineral constituents.

Of the lime estimated to be supplied in the manure in the eight years, only about 12½ per cent. was obtained in the total produce of those years, about 9 per cent in the next six, and little more than 4 per cent. in the last six years, making in all only about 25½ per cent. in the twenty years. Deducting the yield in the unmanured produce, however, there was an increase obtained representing only 3½ per cent. of the amount supplied during the first period, little more than 2 per cent. in the second period, and a small fraction of 1 per cent. in the third period, or a total of less than 6 per cent. in the twenty years.

Of the magnesia the proportion was much larger, that in the total twenty years' produce representing 70 per cent., and the increased yield about 21 per cent., of that supplied.

Of the potash the produce contained, in the three periods of eight, six, and six years, 44 per cent., 22½ per cent., and 10½ per cent., in all 77 per cent. But the increased yield, over that from the unmanured plot, was only 30½, 13, and 4½ per cent.; in all, only about 48 per cent. of that supplied. Potash is, at any rate in moderately clayey soils, very little subject to loss by drainage; but it would appear that the unrecovered residue becomes so locked up (or distributed) as to be but slowly available to succeeding crops.

Of soda, there was, in the presence of an abundant supply of potash, even less taken up in the manured than in the unmanured crop during the years of the application. In later years there was some, but comparatively little, increase in the amount compared with that in the unmanured crop.

Of phosphoric acid, in the twenty years about 57 per cent. of the quantity estimated to be supplied was contained in the total produce, whilst the increased yield represented 33 per cent. The residue of the phosphoric acid, like that of the potash, is very little subject to loss by drainage.

Of sulphuric acid there is proportionately a much less increased amount than of phosphoric acid.

Of chlorine, the increased amount found in the produce is, during the years of application of the manure, greater in proportion to the estimated supply than that of any other constituent. Both chlorine and sulphuric acid are very subject to loss by drainage.

Lastly, of silica, the produce of the twenty years contained about 41½ per cent. as much as there was estimated to be supplied of soluble silica in the manure, and the increased yield of it represented about 22 per cent.

The general results may now be summarised. Of the three more important constituents of manure—nitrogen, potash, and phosphoric acid, when these are supplied in farmyard manure, the nitrogen is recovered in the least proportion in the increase of the crop for which it is supplied. It leaves a large determinable residue within the soil, which, however, is very slowly available to succeeding crops; and, finally, it is subject to serious loss by drainage, and probably by evolution into the atmosphere also. The potash so supplied is recovered in increase in much greater proportion during the years of the application, in much greater, though still rapidly decreasing proportion, in subsequent years, and is very little subject to loss by drainage. The phosphoric acid again, is recovered in much greater proportion than the nitrogen, but not in so large a proportion as the potash; it, too, like potash, is but little subject to loss by drainage.

The much less immediate effect of a given amount of nitrogen when supplied in farmyard manure than when in ammonia-salts or nitrate of soda, the consequent necessity to supply so much more in that form to obtain a given result, and the very slow action of the remaining residue, are important factors in the scientific explanation of the practically recognised much lower money value of a given amount of nitrogen so supplied.

Reverting now to plot 1, the results on which have already been given in Table XLVII., page 190, it remains to point out the difference in effect when, besides the farmyard manure, 200lb. of ammonia-salts were also annually applied per acre, both over the eight years of the application of the farmyard manure, and over the next twelve years of the action of the residue.

The ammonia-salts caused the herbage to assume a darker green colour; gramineous species became more, and both leguminous and miscellaneous species less prominent, than either on the unmanured plot 3, or on plot 1 with farmyard manure alone. Compared with the latter, in the early years, Poa trivialis and Bromus mollis were even more prominent, as also was Dactylis glomerata, and these three grasses made up a large proportion of the total produce. During the later years, as on the plot without ammonia, but in a greater degree, Agrostis vulgaris and Holcus lanatus became very prominent, as also did Anthoxanthum odoratum and Festuca ovina; whilst, on both plots, Poa trivialis, Bromus mollis, and Dactylis glomerata diminished very much. Of leguminous plants, Lathyrus pratensis is the most prominent on both plots, but much more so on plot 2 than on plot 1; and, whilst without ammonia (plot 2) there was nearly 1 per cent. of Trifolium pratense, with it there was none. A much greater number of species, gramineous, leguminous, and miscellaneous, contribute to the produce without (plot 2), than to that with (plot 1), the ammonia-salts.

Although, as is shown in Table XLVII., the increase of produce due to the ammonia-salts was pretty constant, the actual amount of produce per acre was nearly 40 per cent. less over the last six years than over the first eight. Where the farmyard manure was used alone, however, the decline was greater still, being nearly 48 per cent.

The 200lb. of ammonia-salts annually applied are estimated to supply about 41lb. of nitrogen, equal to about 50lb. of ammonia. Yet the figures show that the increased yield of crop represents an average of only about 27½ per cent. of the nitrogen so supplied.

Of mineral matter there was also an increased amount taken up under the influence of the ammonia-salts, though it shows a steady falling off. Over each period there was more lime, magnesia, phosphoric acid, and sulphuric acid, and very much more chlorine, taken up with, than without, the ammonia-salts.

As the increased amounts of lime and magnesia, of potash and soda, and of phosphoric acid, must have had their source in the previous supplies within the soil, or in the residue from the farmyard manure, the action, so far, of the ammonia-salts has been more rapidly to utilise, and, therefore, the more to exhaust, these otherwise dormant stores. But it is probable that, of both the potash and the phosphoric acid supplied in the dung, part remains unliberated from its original condition of combination in the manure, and part becomes so locked up (or distributed) within the soil as to be only very slowly available.

Upon the whole, the evidence goes to show that the effect of the ammonia-salts was to reduce the complexity of the herbage, to render it more gramineous, to increase the amount of produce, and, with this, to draw more upon the mineral stores within the soil. It is also clear that, although the application of the ammonia-salts was the means of turning to account some of the accumulated residue of the mineral constituents supplied in the dung, the limit of the immediately available supply was very soon reached, the remainder becoming less and less rapidly recoverable. It was, in fact, retained in a condition so slowly available as to be of but little effect in increasing immediate crops, and, therefore, of but little practical value, except as a storehouse against exhaustion.

Two points only now remain for consideration, namely, the character of the second crops, and the influence exercised by the nature of the season upon the produce of hay. Both of these are matters of high practical interest.

THE SECOND CROPS.

So far the produce of the first crops only, of each year, has been taken into account. The estimated amounts of second crop, on each plot, in each season, are collected in an elaborate table in an appendix to the paper published in the Philosophical Transactions. But the general character and bearing of the results are sufficiently brought to view in an abstract table, too extensive to be reproduced here, in which are recorded the figures for a selection of the plots only, representing very characteristically different conditions of manuring. The plots for which the results are so given are:

Plot 3. Unmanured every year.

Plot 7. Mixed mineral manure (including potash), without nitrogenous manure, every year.

Plot 9. Mixed mineral manure (including potash), and 400lb. ammonia-salts, every year.

Plot 11. Mixed mineral manure (including potash), and 800lb. ammonia-salts.

Plot 14. Mixed mineral manure (including potash), and nitrate of soda containing the same amount of nitrogen as the ammonia-salts on plot 9.

The particulars given are: The actual amounts of produce of the first crops, the estimated amounts of the second crops, and the proportion of the second to the first reckoned as 100; and at the bottom of the table are stated the averages of the first crops, of the estimated second crops, and the percentage of the second to the first, for the first eight years of the twenty, in every one of which the second crops were fed off by sheep, and their quantities estimated, and for eight subsequent (though not consecutive) years, in seven of which the second crops were fed and estimated, and in the eighth (the last of the twenty), in which the second crops were cut, removed, and weighed. There are also given the particulars of the produce for the same plots for the three years subsequent to the first twenty (1876-78). The salient features presented in this numerical summary may now be noticed.

Although, without manure, the amounts of produce, of both first and second crops, are small, the proportion of second crop to first is greater than under either of the selected manurial conditions; that is, it is greater where the total removed from the land is comparatively small, and where, especially, the variety of the herbage is the greatest, and where, consequently, the possession by the roots of the upper layers of the soil, and the capabilities of food-collection generally, will be the most varied.

Next in proportion of second crops to first comes the mineral-manured plot (7). Here again, the crops, though much larger than without manure, are not really large; but, as without manure, the herbage is complex, and the command by the roots, especially of the upper layers of the soil, will be very varied.

On plot 9, the first crops average about one-and-a-half times as much as with the mineral manure alone, but the estimated average of the second crops is very nearly the same in the two cases. Thus, with the much more luxuriant growth of first crops under the influence of the ammonia-salts, and the much more simple and almost exclusively gramineous herbage, the actual quantity of the second crop is small, and its proportion to the first little more than half as much as without manure, and only about two-thirds as much as with the mineral manure alone.

On plot 14 the first crops averaged more still; they, also, consisted almost exclusively of free-growing (though chiefly other) grasses, and they comprised but few species. With these characters, the second crops averaged even rather less than with the ammonia-salts, and bore a smaller proportion to the first.

In the case of plot 11, with double the amount of ammonia-salts of plot 9, there were upon the whole still larger first crops, and almost exclusively gramineous herbage, which contained, however, a very abnormally high percentage of nitrogen, and, with the obvious excess available, there is here more second crop, and a higher proportion of second crop to first, than with the smaller amount of nitrogenous manure. There is, moreover, a tendency to a greater amount, and proportion, of second crop in the later years.

The general result is that, when (with mineral manure) active nitrogenous manures are used, but not in excessive amount, the increase of the first crop will, in favourable seasons, be such as to leave comparatively little available nitrogenous residue for the second crop; whilst, the produce under such circumstances being characteristically gramineous, and comprising comparatively few species, the condition of the herbage is not very favourable for subsequent growth. The percentage of both mineral matter and nitrogen is generally, however, much higher in the dry substance of the second and less matured produce, than in that of the first and more matured, so that the removal of the second crops is a considerably greater drain upon the resources of the soil than might be suspected from the comparatively small amounts of the produce. It is evident, too, that the actual and relative amounts of second crop depend not only on the balance of available constituents remaining within the soil, and on the climatal conditions, but also on the variety, and the unexhausted condition, of the plants themselves which are comprised in the mixed herbage.

INFLUENCE OF SEASON ON THE PRODUCE OF HAY.

The object of this discussion is to endeavour to trace the connection between certain measurable characters of season on the one hand, and the luxuriance or sluggishness of growth of the mixed herbage on the other, with comparatively little reference to the effects of the different manures.

Common observation recognises a general connection between the characters of the weather as to moisture, heat, and light, and the luxuriance or scantiness of vegetation. When, however, the amounts of growth in different seasons are compared with the usual meteorological records of the period, it at once becomes apparent how complicated is the connection, and how inadequate are such records for a fuller explanation of the differences of result obtained in different seasons. And, however difficult and intricate the subject may be when the growth of a crop consisting of a single species only is concerned, it is far more so when the problem has to deal with the relations of the various climatal conditions to the development of a great variety of species growing together, as in the case of the mixed herbage, and numbering, as they do, from less than twenty to more than fifty, according to the varied manurial conditions provided.

The method adopted is to draw attention to the actual and the comparative characters of season under which some of the largest, and some of the smallest, amounts of produce have been grown. In a series of tables are recorded the actual amounts of produce of hay per acre (first crops) on the same five selected plots as were taken (page 206) to illustrate the second crops, the monthly rainfall in inches (at Rothamsted), the number of days in each month when the rainfall exceeded 0·01in., together with the monthly mean maximum temperature, the monthly mean minimum temperature, the monthly mean temperature, and the monthly mean range of temperature, all at Greenwich. Further, in the respective tables, there are given, for each season, the total rainfall, the total number of days on which 0·01in. or more fell, and the means for each item of temperature:—

1. For the total 12 months; July to June inclusive;
2. For 4 months—July to October;
3. For 4 months—November to February;
4. For 4 months—March to June;
5. For 3 months—April to June;
6. For 2 months—April and May.

With each of the five very different conditions of manuring (on plots 3, 7, 9, 11, 14) the year 1869 gave the highest amount of produce. On the other hand, 1870 gave, with two out of the five conditions of manuring, the lowest produce, with two others the lowest but one; but the remaining or nitrated plot was an exception, giving, in this year of drought, 1870, an abnormally high produce for the season—a fact which was considered when the general results on plot 14 were under discussion. There can be no hesitation, therefore, in taking the season of 1869 as that of the highest productiveness of the twenty, and that of 1870 (with the exception mentioned) as one of the lowest productiveness; the next in order in this latter respect being 1874. The produce of these two most contrasted seasons is set forth in Table LIV., page 211, where also a comparison is made with the average of the twenty years, and the deficiency in 1870 compared with 1869.

A very full table, not given here, shows some of the meteorological conditions under which the two very different crops were grown.

The lowest line in Table LIV. shows that (excluding the nitrate plot 14) there was an average yield per acre of nearly 4000lb. (about 1¾ tons) more hay in 1869 than in 1870;

and without manure, and with purely mineral manure, the excess amounted to more than the average produce of those plots.

TABLE LIV.—PRODUCE OF HAY PER ACRE ON SELECTED PLOTS. AVERAGE OF THE 20 YEARS; PRODUCE OF 1869, THE YEAR OF HIGHEST PRODUCTIVENESS; PRODUCE OF 1870, THE YEAR OF LOWEST PRODUCTIVENESS; DIFFERENCE OF EACH FROM THE AVERAGE; AND DIFFERENCE OF THE ONE FROM THE OTHER.

	Plot 3. Unmanured.	Plot 7. Mineral Manure alone.	Plot 9. Mineral Manure and 400lb. Ammonia-salts.	Plot 11. Mineral Manure and 800lb. Ammonia-salts.	Plot 14. Mineral Manure and Nitrate of Soda.	Means.
	lb.	lb.	lb.	lb.	lb.	lb.
Average, 20 yrs., 1856-75	2383	3958	5711	6726	6407	5037
1869	4256	6124	7700	8610	8526	7043
1870	644	1968	3306	5150	6300	3474
+ or − average 1869	+1873	+2166	+1989	+1884	+2119	+2006
+ or − average 1870	−1739	−1990	−2405	−1576	− 107	−1563
1870 less than 1869	−3612	−4156	−4394	−3460	−2226	−3569

The character of the weather of 1868-9 is thus summarised: After five months of unusually high temperature (May to September, 1868), and unusual drought during the first three of them, the two following months (October and November, 1868) were again dry, but cold. The three winter months were very warm, and all more or less, but December especially, very wet. The result was an unusual winter growth of grass. The dry and cold weather of March, however, checked vegetation; but, with its early start and marked progress in the winter, it recovered rapidly under the influence of the very warm and sufficiently wet weather of April. The two remaining months of the grass season were, however, unusually cold, May being at the same time very wet, but June dry, a condition which was compensated by the previous abundance of moisture; whilst, although the ruling temperatures were low for those months, they were yet actually sufficient for active vegetation. The result was luxuriant and succulent, though not maturing, growth. Indeed, according to notes taken on the ground, the plots generally manifested great luxuriance; but the most prominent plants, whether gramineous, leguminous, or miscellaneous, were much more backward than usual at the time of cutting.

Thus, the excessive produce of grass in 1869 was due not so much to the climatic conditions during the limited period of really active accumulation and above-ground growth, as to the preceding very favourable, instead of as usual detrimental, conditions throughout the three winter months, thus bringing the herbage unusually forward, and rendering it more capable of turning to the best account such climatic elements of growth as followed. This result is somewhat analogous to that observed in the case of the Rothamsted experiments on the continuous growth of wheat; the seasons of extraordinary productiveness of that crop having been marked rather by moderately favourable conditions throughout, than by specially favourable ones during the period of most active above-ground growth.

The conditions which prevailed in 1870, the year of least productiveness, must now be examined. After the enormous first crops of 1869 less than average second crops were grown. Not only would there be comparative exhaustion of manurial constituents, but, succeeding upon the dry weather of June, and the cold weather of both May and June, there was a considerable deficiency of rain in July and August, but little more than the average in September, and again a deficiency in October; and, with the continued lack of rain in July and August, July was warmer, but August for the most part unseasonably colder, than usual; whilst September, with its fair amount of rain, was generally warmer, and October, with its defect, at times much colder than the average.

The autumn conditions were therefore, upon the whole, adverse to growth. Over the five months—November, 1869, to March, 1870, inclusive—the rain gauge indicated more than the average total fall, though there was a considerable deficiency in January. There were heavy and continuous falls of rain in November and December, with great fluctuations of temperature, some very warm, and some very cold weather, and numerous gales. The first three months of 1870 again were marked by frequent alternations of warm and very cold weather, the colder periods prevailing, and being sometimes very severe. Snow was frequent, but the total fall was deficient in January, and but little above the average in February and March. Vegetation generally was very backward, and grass land was very brown and bare. April, May, and June, the three months of most active accumulation and growth, were largely deficient in rain, and with the exception of about a fortnight at the end of April and the beginning of May, when the weather was cold and cloudy, the whole period was unusually warm and sunny, the three months together being not only much warmer than the average, but very unusually deficient in rain. The day temperatures especially were high, though the night temperatures were, in April and May, low; and throughout the three months the degree of humidity of the atmosphere was considerably below the average.

Thus, after an autumn very deficient in rain, and fluctuating as to temperature, a winter and early spring very stormy, very fluctuating as to temperature, in fact very inclement, and vegetation consequently very backward to start with, the three months of most active above-ground growth were very unusually dry, very unusually hot in the days, and frequently colder than the average in the nights. It was under these conditions that the smallest crop of the twenty years was obtained.

Upon the whole then, the registered meteorological conditions of the season of least productiveness more obviously account for the deficient crop, than do those of the previous season account for its excessive yield. In the case of the crop of 1870, the conditions previous to the period of active growth were strikingly unfavourable for the herbage, and the period of active growth was itself strikingly adverse, both in its extreme dryness, and in its coincident high day and low night temperatures. In the case of the excessive, but succulent and immature, growth of 1869, the climatic conditions previous to the period of most active vegetation were obviously very favourable; but those of the period of active above-ground growth itself were such as would only conduce to great luxuriance provided there were an already forward condition of the herbage.

The years 1868 and 1874 are also noticed, the former being perhaps the second in order of productiveness and the latter the second in unproductiveness. Table LV. summarises the results in these two years, and may be usefully compared with Table LIV., page 211.

TABLE LV.—PRODUCE OF HAY PER ACRE ON SELECTED PLOTS. AVERAGE OF THE 20 YEARS; PRODUCE OF 1868, THE YEAR SECOND IN ORDER OF PRODUCTIVENESS; PRODUCE OF 1874, THE YEAR SECOND IN ORDER OF UNPRODUCTIVENESS; DIFFERENCE OF EACH FROM THE AVERAGE; AND DIFFERENCE OF THE ONE FROM THE OTHER.

	Plot 3.	Plot 7.	Plot 9.	Plot 11.	Plot 14.	Means.
	lb.	lb.	lb.	lb.	lb.	lb.
Average, 20 yrs., 1856-75	2383	3958	5711	6726	6407	5037
1868	1960	4264	6622	7616	7728	5638
1874	1412	3088	3290	3540	5484	3363
+ or − average { 1868	− 423	+ 306	+ 911	+ 890	+ 1321	+ 601
+ or − average { 1874	− 971	− 870	− 2421	− 3186	− 923	− 1674
1874 less than 1868	− 548	− 1176	− 3332	− 4076	− 2244	− 2275

Another table gives a very full abstract of the meteorological conditions of the two years under notice, and, as before, the relation of the season to the yield of crop is discussed, but the briefest summary must suffice here.

The season second in order of productiveness was characterised by unusually high temperatures throughout the whole period of growth, with a sufficiency of rain up to the end of April, conditions which brought the herbage very early forward, and rendered it comparatively independent of the extreme heat and drought of the months of May and June, which would otherwise have been fatal at that period, and which were, in fact, very injurious where the conditions of manuring had not been such as to bring the vegetation sufficiently forward previously.

It is a curious result that the year of the lowest produce of the twenty, 1870, was the one of the most extreme heat and drought of the series, and that the year of the highest produce but one, 1868, was only second to 1870 in heat and drought of the growing period. But there was this difference: the winter and early spring of 1870 had been very adverse, the herbage was in a very backward state, and the heat and drought commenced a month earlier; whereas, from the commencement of 1868, for a period of nearly four months, the conditions both as to heat and moisture were favourable, and it was not until May that the heat and drought set in, then serving to elaborate and mature, rather than materially to check, vegetation in such condition of luxuriance and forwardness.

With regard to the season second in order of unproductiveness, it appears that, although the winter and early spring of 1873-4 were, upon the whole, considerably warmer than usual, there were periods of some severity as to temperature, and the whole period was very deficient in rain; so that, instead of the warmth of the usually cold months availing to bring vegetation forward, it remained very backward when it was overtaken by the unfavourably cold days, and the very unusually severe frosty nights, of the greater part of May, whilst the short period of warmer weather which then set in was unaccompanied by sufficient moisture, and the herbage was already too much damaged to recover. According to notes taken on the ground at the time, the foliage of the grasses became spotted, and the earlier flowering stems were bleached, and in many cases killed. The greatest damage was done on the plots highly manured with ammonia-salts, where Dactylis glomerata, which was both abundant and forward, suffered very much.

The four selected seasons most strikingly illustrate the intricacy and difficulty of the attempt to trace the relation between the amount of growth of the mixed herbage of grass land, and such meteorological conditions as are sufficiently recorded. Very dissimilar climatal conditions characterised the two seasons of highest productiveness, and again very dissimilar ones those of lowest productiveness. The character of the produce was also very different in the two cases of the largest crops, and again very different in the two of the smallest crops.

Taking a comprehensive view of the four seasons, it is apparent that in both seasons of high productiveness the period prior to that of most active above-ground growth had brought the herbage into an unusual state of forwardness; when, in the one, abundance of rain, with, upon the whole, low temperatures, gave great luxuriance, but comparatively leafy, succulent, and immature produce; whilst, in the other, the luxuriant early growth was followed by both unusual drought and unusual heat, yielding quantity by virtue of high development and maturation, as distinguished from succulence and immaturity. As in both the cases of high productiveness the period antecedent to that of most active growth had been favourable, so in both those of very defective growth they had been very unfavourable. The winter and early spring of 1870 had not, upon the whole, been deficient in rain, but the period had been extremely variable as to temperature, frequently very inclement, and, upon the whole, colder than usual. The herbage was, from these causes, very backward at the commencement of the active growing period. April, May, and June followed, with a great deficiency of rain, very high day and low night temperatures, yielding very stunted and prematurely ripened produce. The winter and early spring of 1874 had, on the contrary, been very unusually deficient in rain, whilst the temperatures had ruled higher than the average, both day and night, especially the latter, and the already backward herbage was very materially damaged, yielding not only checked and stunted, but reallv damaged crops.

It has already been shown how greatly both the botanical and the chemical composition of mixed herbage vary according to the description of manure applied; and the foregoing typical illustrations of the effects of the varying climatic conditions of different seasons clearly indicate how different, both botanically and chemically, will be the character of the produce dependent on the character of the seasons. In fact, a given quantity of gross produce of the mixed herbage may be one thing in one season and quite another in another season, both as to the proportion of the different species composing it and as to their condition of development and maturity.

IX. — BOTANICAL RESULTS OF EXPERIMENTS ON THE MIXED HERBAGE OF PERMANENT MEADOW. (*a*)

There is at Rothamsted nothing which will more impress the visitor than the seven acres of meadow land in the Park, the many years' experiments upon which with different manures constitute the subject of this memoir. The twenty parallel plots into which this area is divided appeal at once and forcibly to the eye by the obvious differences in their herbage. A plot here with rich green grasses waving luxuriantly upon it; another, on which the yellow meadow vetchling apparently constitutes the leading feature; a third, irregular, patchy, and much afflicted with sorrel; and yet another, on which, at the time of my visit (August), the white-flowered umbels of the earth-nut put everything else in the shade—these and the like appearances convince with an eloquence which the pen is powerless to imitate.

The land in Rothamsted Park has probably been laid down with grass for some centuries. No fresh seed has been artificially sown within the last fifty years certainly, nor is there record of any having been sown since the grass was first laid down. The experiments commenced in 1856, at which time the herbage appeared to be of uniform character. With

(*a*) "Agricultural, Botanical, and Chemical Results of Experiments on the Mixed Herbage of Permanent Meadow, conducted for more than twenty years in succession on the same land." Part ii., the Botanical Results. By Sir J. B. Lawes, Bart., F.R.S., Dr J. H. Gilbert, F.R.S., and Dr. M. T. Masters, F.R.S. Phil. Trans., part iv., 1882. Pp. about 250.—(This notice is taken from an article which I contributed to *Nature*, vol. XXIX., page 81.—W. F.)

few exceptions the same description of manure has been applied year after year to the same plot; and two plots, the third and twelfth, have been continuously unmanured. For the first nineteen years the first crop only was cut and carried away, and the second crop was usually fed off by sheep who were receiving at the time no other food. Of recent years it has been more and more the practice to make the second crop also into hay, and it is intended to adhere to this plan in future, weather permitting.

The produce of every plot is weighed as hay, and the result calculated per acre. Taking the average of the first twenty years, the unmanured plots, 3 and 12, gave the lowest yields of all, 21¼ and 24cwt. respectively. Next above these is plot 5, manured with ammonia-salts at the rate of 400lb. per acre per annum, the yield giving an annual average of 26¼ cwt. per acre. The highest average recorded, 62½cwt. per acre, resulted from a mixed manure, containing 500lb. sulphate of potash, 100lb. sulphate of soda, 100lb. sulphate of magnesia, 3½cwt. superphosphate of lime, 600lb. ammonia-salts, and 400lb. silicate of soda,—a tremendous dressing, by the way. The average yields on the rest of the plots, each one of which received different manurial treatment from that of the others, range themselves between these extremes.

But the mere quantitative estimation of the yields per acre was a comparatively simple task to that of making a qualitative botanical examination of each crop. The proximate analysis was into the three classes of gramineous herbage, leguminous herbage, and miscellaneous herbage, the last-mentioned containing all plants not referable to the Gramineæ or the Leguminosæ; and even this task would not be a very difficult one. But when it is stated that in certain seasons a complete botanical analysis was made, whereby each species of plant was separated from all the others, then the irksomenesss of the work will be appreciated. For the details of these analyses I must refer to the memoir itself, but the following is worth reproducing. "To quote an extreme case in illustration of the difference in the character of the herbage, and of the difference in the degree of difficulty of separation accordingly, it may be mentioned that whilst a sample of 20lb. from one plot in 1872 only occupied from four to five days in botanical analysis, a sample of equal weight from another plot in the same year occupied thirty days."

The total number of different species of plants that have been detected on the plots is 89; of these, 20 are gramineous, 10 are leguminous, and the remaining fifty-nine belong to miscellaneous orders. The 89 species comprise 59 dicotyledons, 26 monocotyledons, and 4 cryptogams, three of which are mosses (Hypnum); they are arranged under 63 genera and 22 orders. Of the miscellaneous plants there are 13 species of Compositæ, 6 of Rosaceæ, 5 each of Ranunculaceæ and Umbelliferæ, 3 each of Labiatæ, Polygonaceæ, Liliaceæ, Caryophylleæ, Scrophulariaceæ, and Musci, 2 each of Rubiaceæ and Plantagineæ, and 1 each of Cruciferæ, Hypericineæ, Dipsaceæ, Primulaceæ, Orchidaceæ, Juncaceæ, Cyperaceæ, and Filices. Six genera only were represented by more than one species; these were Ranunculus, 5 species, Rumex 3, and Potentilla, Galium, Leontodon, and Veronica, 2 each. The 20 species of grass comprise 14 genera; Festuca is represented by 4 species, Avena by 3, Poa by 2, and Anthoxanthum, *Alopecurus*, Phleum, *Agrostis*, Aira, *Holcus*, Briza, Dactylis, Cynosurus, *Bromus*, and Lolium by 1 each. The fact that the four genera whose names are here italicised were only represented by one species each serves to indicate somewhat the nature of the land. Had it been wet or marshy in parts, Alopecurus geniculatus might have been looked for as well as Alopecurus pratensis. Had not the plots been quite away from hedgerows, several species of Bromus might have accompanied Bromus mollis, whilst Brachypodium sylvaticum might also have been looked for. The total absence of Glyceria further shows the fairly dry character of the soil. Lastly, the 10 species of Leguminosæ fall under 5 genera — of Trifolium 4 species, Lotus and Vicia 2 each, Lathyrus and Ononis 1 each.

Ten species of grasses occur on all the plots: Anthoxanthum odoratum, Alopecurus pratensis, Agrostis vulgaris, Holcus lanatus, Avena flavescens, Poa pratensis, Poa trivialis, Dactylis glomerata, Festuca ovina, and Lolium perenne. Festuca elatior was only found in one plot, and Festuca loliacea in two. Phleum pratense occurred in about one-fourth the number of plots, Aira cæspitosa in about one-half, Briza media, Cynosurus cristatus, Festuca pratensis, and Bromus mollis in sixteen or seventeen. No leguminous plant occurred in all the plots, but Lathyrus pratensis was found in nineteen plots, Trifolium repens and Trifolium pratense in seventeen, Lotus corniculatus in sixteen, and Trifolium minus, Trifolium procumbens, Lotus major, Ononis arvensis, Vicia sepium, and Vicia Cracca only in one each.

These details will serve to indicate the nature of the flora of the plots. Certain miscellaneous plants common on many old pastures in this country are conspicuous by their absence. The dry and level character of the meadow will account for the absence of Caltha and Juncus. No species of Geranium is recorded. But the most noteworthy fact appears to be the absence of certain scrophulariaceous genera, which are by no means uncommon on old grass lands, namely, Bartsia, Euphrasia, and Rhinanthus. The quality of the land is probably too good for the first two, and the application of manure would certainly be against Euphrasia, but Rhinanthus Crista-galli (yellow rattle) is very common on old meadows, as, for example, in Derbyshire and Worcestershire.

The object which the authors kept in view in writing this section of their report was, in their own words, "to show both the normal botanical composition of the herbage, and the changes induced by the application of the different manuring agents, and by variation in the climatal conditions of the different seasons; and, as far as may be, to ascertain what are the special characters of growth above ground or under ground, normal or induced, by virtue of which the various species have dominated, or have been dominated over, in the struggle which has ensued." At the outset it was noticed that those manures which are most effective with cereals grown on arable land, were also most active in increasing the quantity of grass amongst the herbage, and that the manures which are most beneficial to beans or clover produced the greatest proportion of leguminous herbage. Thus, the highest gramineous produce resulted from a highly nitrogenous manure, such as ammonia-salts or nitrate of soda, with alkaline-salts, particularly potash; but side by side with the increase in the total gramineous herbage, there was a decrease in the actual number of species of grass. On the other hand, the highest percentage of leguminous produce was the result of a mixed mineral manure with potash. The percentage (by weight) results on the following plots illustrate these points:

	Plot 7.	Plots 3 and 12.	Plot 11.
Gramineæ	61·03	67·43	95·91
Leguminosæ	23·06	8·20	0·01
Other Orders	15·91	24·37	4·08
	100·00	100·00	100·00

Plot 7 was the most favourably manured for leguminous produce, it received mixed mineral manure alone, including potash; plots 3 and 12 were the two unmanured ones; plot 11 was the most favourably manured for gramineous produce, it received 800lb. ammonia-salts per acre, with mixed mineral manure, including potash.

Special observations and complete botanical separations made at intervals of five years to determine the influence of seasonal variations show that "a given quantity of the produce grown under the same conditions as to manuring might be composed very differently in two different seasons."

The influence due to the special medium through which a particular plant-food, such as nitrogen, is presented to the plant, is aptly illustrated in the following words: "Because a particular grass, or other plant, is little benefited by ammonia-salts for instance, it does not follow that it will not be favoured by nitrates; nor, because if while growing in association with other species it may not be specially benefited by a particular manure, does it follow that it would not derive advantage from the same substance when growing separately."

Nearly all the plants on the plots are perennials, very few are annuals, Bromis mollis being the only case amongst the grasses. The advantage possessed by deep-rooting over surface-rooting plants was well brought out in the droughty season of 1870, when the latter suffered considerably from lack of moisture. The locomotive power of underground stems is of great use to some plants; "the stock continues to grow at one end, year after year, the opposite end gradually dying away. In the course of a few years the plant therefore occupies quite a different position from that which it at first had." Notwithstanding the general rule that the chief effect of nitrogenous manures is to favour the extension of foliage and give it depth of colour, whilst that of mineral manures is to encourage stem formation and the production of seed, and notwithstanding that excessive nitrogenous manuring prolongs the development of the vegetative organs till perhaps the resources of the plant are exhausted or the season is over, whilst excess of mineral manures may induce premature ripening, yet so far as the experiments have gone no absolute change in the distinctive form of any plant has been effected by the prolonged use of the different manures, though changes of degree are sometimes very marked, as in the tufts of Dactylis glomerata.

The battle for life between the various species of plants growing in the meadow is dependent much less on the chemical composition of the soil than on its physical character, its capacity for holding water, and its permeability to roots. The immediate source of victory lies very generally in the powerful root-growth of the survivors, the term "root" here covering all kinds of underground stem. The various influences affecting the struggle for existence amongst meadow plants are discussed by the authors in a fascinating manner, and this part of the memoir is of special value to the botanical student.

Every plant occurring on the plots is dealt with individually, and in the case of each grass and leguminous plant and of the more commonly occurring weeds, a table showing the relative predominance is given. The fact that plants closely allied morphologically may yet differ widely in their physiological endowments is strikingly illustrated by the two species Poa trivialis and Poa pratensis. These two plants, sprung at some former period from a common ancestor—for this, we presume, is the morphological significance of their being placed in the same genus—differ only in the most trivial points: Poa pratensis (smooth-stalked meadow grass) is smooth, stoloniferous, and has a blunt ligule; Poa trivialis (rough-stalked meadow grass) is rough, has no stolons, and possesses a long pointed ligule. We read that "the stolon-bearing Poa pratensis is especially benefited by nitrogenous manure in the form of ammonia-salts (in combination with mineral manure), but not at all by nitrate of soda, whereas the more finely-rooted and non-stoloniferous Poa trivialis has declined markedly on the ammonia plots, but has remained very prominent on the nitrate plots, especially where the larger amount of nitrate was used with the mixed mineral manure." Thus in 1872, on plot 9 (mineral manure and ammonia-salts), Poa pratensis gave 22·67 per cent of the total produce, and Poa trivialis only 0·64; on plot 14 (mineral manure and nitrate of soda) Poa trivialis gave 24·76, and Poa pratensis only 2·57 per cent. It is suggested that the relatively shallow-rooting Poa trivialis predominates on the nitrate plots by reason of its fine surface-roots arresting and taking up the nitrate before it has had time to penetrate too deeply; this plant invariably makes rapid growth upon the application of the nitrate of soda in the spring.

The remaining portion of the paper is devoted to a discussion of the botany of each separate plot in each season of complete botanical separation, and is carried out with the same elaborate detail as the earlier portion. No one can read this memoir without being impressed with the great power, too frequently overlooked, possessed by the subterranean members of the plant body in deciding the struggle for existence; much of the internecine warfare is carried on in the dark.

Such a splendid series of experiments on grass land has never before been consummated, and the results deserve the most careful study not only of the agriculturist, but of the botanist, the chemist, and the evolutionist. It may perhaps be long before the great lessons learnt in Rothamsted Park have filtered down to those to whom they should be of most practical value, but I do not despair of a time coming when the intelligent manuring of grass lands for very specific objects will form a part of ordinary agricultural practice. Those who put their hands to the plough in the field of agricultural research must be content to trudge along, laboriously and unnoticed, in the furrow. Their discoveries cannot be made in a week, or a month, as are many in electricity or in chemistry, but, like those at Rothamsted, where the investigations were commenced more than half a century ago, they can only be looked for, even after the expenditure of much thought and of unflagging industry and perseverance, as

"the long result of Time."

INDEX.

1888.

A

CATALOGUE OF BOOKS

RELATING TO

Angling, Boating, Cricket, Farming, Gardening, Hunting, Shooting, Tennis, Travel, Yachting, &c.,

USEFUL FOR

COUNTRY GENTLEMEN, TRAVELLERS, ETC.,

PUBLISHED BY

HORACE COX,

"THE FIELD" OFFICE, 346, STRAND, LONDON, W.C.

*** *Orders for any of the following works, with postage stamps or post-office order (payable at the Money Order Office, 369, Strand) for the amount, should be sent to* HORACE COX, *Publisher, at the above address, or they may be obtained by order of any bookseller.*

NOTE.

I BEG to call the attention of Country Gentlemen, Travellers, Sportsmen, Farmers, and others to the works quoted in this Catalogue. They are written by authors who are well known and acknowledged authorities on their respective subjects.

The illustrations have been intrusted to competent artists, and neither pains nor expense have been spared to make the works as complete as possible.

HORACE COX,

Publisher.

A

CATALOGUE OF BOOKS

PUBLISHED BY

HORACE COX.

Second Edition, Greatly Enlarged.

Royal 4to., bevelled boards, gilt edges, price 15s., by post 15s. 9d.

PHEASANTS:

THEIR

NATURAL HISTORY AND PRACTICAL MANAGEMENT.

BY

W. B. TEGETMEIER, F.Z.S.,

(*Member of the British Ornithologists' Union.*)

AUTHOR OF "THE NATURAL HISTORY OF THE CRANES," &c.

Illustrated with numerous full-page engravings drawn from Life by T. W. WOOD.

CONTENTS.

The Natural History of the Pheasants, Habits, Food, Structure, &c.; Management in Preserves and in Confinement, with detailed descriptions of the Different Species adapted for the Covert and the Aviary, and an account of their Diseases and Transport.

NOTICES OF THE SECOND EDITION.

From Yarrell's "British Birds," fourth edition.—"For further details, as well as for instructions as to the management of pheasants, both in the covert and the aviary, and the disorders to which they are liable, the reader is referred to Mr. Tegetmeier's excellent work, to which the editor is under great obligations."

From the *Pall Mall Gazette.*—"This new and sumptuous edition contains so large an amount of fresh matter that it may be regarded, practically, as another work. In its own way, it is quite exhaustive. Illustrated by admirable and lifelike full-page illustrations. On the technical details of rearing and preservation, Mr. Tegetmeier will be found a thoroughly trustworthy and scientific guide."

From the *Daily Telegraph.*—"Both in its description and practical aspects, the treatise is admirable."

"THE FIELD" OFFICE, 346, STRAND, W.C.

IN TWO VOLUMES,

Demy 8vo., price 15s. each, by post 16s.,

THE

MODERN SPORTSMAN'S GUN AND RIFLE,

INCLUDING

GAME AND WILDFOWL GUNS, SPORTING AND MATCH RIFLES AND REVOLVERS.

Vol. I.—Game and Wildfowl Guns.
Vol. II.—The Rifle and Revolver.

By J. H. WALSH,

"STONEHENGE," EDITOR OF "THE FIELD,"

Author of "Dogs of the British Islands," "The Greyhound," "British Rural Sports, &c.

PRESS OPINIONS ON VOLUME I.

"A perusal of Mr. Walsh's book has forced upon us the conclusion, one that will be shared by nearly every reader, that it is indisputably the standard work on the subject, and is likely long to remain so—a position it richly merits. Sportsmen will anxiously look forward to the second volume of the work, for there is every reason to anticipate that the same high standard will be maintained, and that the rifle will receive as complete an exposition as the 'Game and Wild Fowl Guns.' We are only fulfilling a duty to the public when we say that no man connected in any way with guns or gunnery should be without a copy of Mr. Walsh's masterly volume."—*The Birmingham Daily Gazette*, Nov. 21, 1882.

"It will be seen that the work contains a variety of hints which may be useful to intending purchasers of guns, so that we can confidently recommend an intelligent glance through it as likely to save money and prevent disappointment."—*Saturday Review.*

"Taking the work as a whole, the sportsman will find in it much information on guns, shot, and kindred topics."—*Pall Mall Gazette.*

"The most complete work that has yet been written on sporting guns."—*St. James's Gazette.*

"For breadth of view and completeness this treatise could hardly be excelled. It has, moreover, the advantage of reporting authoritatively on the very latest improvements, both as regards weapons and powder and shot, all which objects of a sportsman's consideration seem to be susceptible of indefinite progress."—*Daily News.*

"With such a guide as this, all who appreciate sport will be able to enjoy it fully, and, what is of importance, will be able to avoid much of the danger attending the use of imperfect weapons.—*The Era.*

Price 1s., by post 1s. 1d.

PASTURES, OLD AND NEW:

A Plea for the Improvement of Old Turf, Better Systems of Grassing-down, and the Prolonged Tenure of Alternate Husbandry Grass Layers.

By JOSEPH DARBY.

SECOND EDITION, *large post 8vo., price 5s., by post 5s. 3d.*

ANGLING.

By FRANCIS FRANCIS.

Author of "A Book on Angling," "By Lake and River," "Hot-Pot," &c.

CONTENTS.

Post 8vo., in cloth, price 5s., by post 5s. 4d.

HOT-POT.

MISCELLANEOUS PAPERS

BY FRANCIS FRANCIS,

Author of "A Book on Angling," "By Lake and River," "Angling," &c

CONTENTS.

Demy 8vo., with folding plates and full-page illustrations printed on toned paper, price 21s., by post 21s. 9d.

MODERN WILDFOWLING.

BY

LEWIS CLEMENT,

"WILDFOWLER."

CONTENTS.

OPINIONS OF THE PRESS.

"An excellent work indeed, and full of capital illustrations, is 'Modern Wildfowling;' to recommend it aright I should have, if I were clever enough, and it did not already exist, to invent the famous phrase, 'a book no gentleman's library should be without.'"—*Truth*, March 17, 1881.

"This book deals not only with the various modes of approaching or decoying, and killing wildfowl of all kinds, but enters into minute details upon the construction of punts, both single and double handed; sails; punt guns, muzzle-loading as well as breechloading; recoil apparatus; and shoulder guns of all patterns, with the varying loads required for different bores. In addition to this are several chapters devoted to a narration of the adventures of the author while in pursuit of wildfowl, both at home and abroad—which are very pleasant reading. . . . . With the addition of a good index, sportsmen will have in this work a capital *vade mecum* on the art of wildfowling.—*The Zoologist* for November, 1880.

Now ready, royal 8vo., price 10s. 6d., by post 11s.

HORSE BREEDING RECOLLECTIONS.

BY

COUNT G. LEHNDORFF,

CONTAINING:

Notes on the Breeding of Thoroughbreds—In-breeding and Out-crossing—Pedigrees of all the Principal Sires—and Genealogical Tables of Celebrated Thoroughbreds.

Post 8vo., price 7s. 6d., by post 8s.

MOSS FROM A ROLLING STONE;

MOORISH WANDERINGS AND RAMBLING REMINISCENCES.

BY

CHARLES A. PAYTON.

"Sarcelle" of "The Field," &c., Author of "The Diamond Diggings of South Africa."

Price 5s. cloth, by post 5s. 4d.

A Year of Liberty; or, Salmon Angling in Ireland.

BY W. PEARD, M.D., LL.B.

Price 2s. 6d., by post 2s. 8d., in limp cloth.

RABBITS FOR PROFIT AND RABBITS FOR POWDER.

A Treatise upon the New Industry of Hutch Rabbit Farming in the Open, and upon Warrens specially intended for Sporting Purposes; with Hints as to their Construction, Cost, and Maintenance.

By R. J. LLOYD-PRICE.

Price 6d., by post 6½d.

THE "FIELD" LAWN TENNIS UMPIRES' SCORE-SHEET BOOK

(with Instructions for the use of Umpires).

Adapted for the use of Umpires and Players, as used at the Championship Meetings.

THIRD EDITION. *Large post 8vo. price 7s. 6d. cloth, by post 7s. 10d.*

FACTS AND USEFUL HINTS

RELATING TO

FISHING AND SHOOTING:

TO WHICH IS ADDED

A LIST OF RECIPES FOR THE MANAGEMENT AND CURE OF DOGS IN DISEASE.

Edited by I. E. B. C.,

Editor of "The Gamekeeper's and Game Preserver's Account Book and Diary," &c.

CONTENTS.

FISHING.

Baits—Fish—Fish Hatching—Flies and Fly Making—Flights—Floats—Gut—Lines—Miscellaneous—Nets—Ponds and Streams—Rods—Wading Boots—Wax.

SHOOTING.

Birds and Beasts — Breeding — Coverts — Deer—Dogs—Ferrets—Foxes—Guns—Kennel—Miscellaneous—Nets—Preserving—Rabbits—Rifles—Traps—Vermin.

APPENDIX.—Diseases of Dogs.

In post 8vo., with Illustrations, price 3s. 6d., by post 3s. 9d.

THE PRACTICAL MANAGEMENT OF FISHERIES.

A BOOK FOR PROPRIETORS AND KEEPERS.

BY FRANCIS FRANCIS,

Author of "Fish Culture," "A Book on Angling," "Reports on Salmon Ladders," &c. &c. &c.

CONTENTS.

Chap.
I.—Fish and Fish Food.
II.—How to Grow Fish Food and how to Make Fishes' Homes.
III.—On the Management of Weeds and the Economy of Fishing.
IV.—The Enemies of Trout and how to Circumvent them.
V.—The Artificial Incubation of Ova.
VI.—On the Rearing of Fry and the Conduct of Ponds, Stews, &c.
VII.—Some Hatcheries.
VIII.—Coarse Fish.
IX.—On Salmon and Trout Ladders and Passes.
APPENDIX.—Notes, &c.

Price 2s. 6d. by post 2s. 9d.

GAME REGISTER,

GIVING AN ACCOUNT OF EACH HEAD OF GAME KILLED, AND HOW DISPOSED OF.

Containing also Divisions for Registering Sporting Engagements and General Observations.

"THE FIELD" OFFICE, 346, STRAND, W.C.

Now ready, quarto, price 5s., by post 5s. 6d.

THE

GAMEKEEPER'S AND GAME PRESERVER'S Account Book and Diary.

By I. E. B. C.,

Editor of "Facts and Useful Hints relating to Fishing and Shooting," "The Angler's Diary," &c.

ITS SECTIONS COMPRISE—

THE SHOOTING AND ITS GUARDIANS.

MEMORANDUM OF AGREEMENT.

RECEIPTS AND PAYMENTS.

VERMIN DIARY—
General Summary.

POULTRY DIARY—
Receipts and Payments.
General Balance Sheet.

PHEASANT DIARY—
Receipts and Expenses.
General Balance Sheet.

DOG DIARY—
Kennel Names, Ages, Value, &c.
Kennel Occupants at the beginning of each Quarter of the Year.
Produce Register—Bitches.
Stud Register.
Pedigrees.
Receipts and Expenses.
General Balance Sheet.

GAME DIARY—
Total Summary of the Season.
Produce of the Beats or Coverts.
Tenants, &c., to whom Game should be given.
Inventory of Appliances, &c.

STOCK VALUATION.

General Balance Sheet for the Year.

In handy pocket size, price 1s. 6d., by post 1s. 7d.

THE GAMEKEEPER'S SHOOTING MEMORANDUM BOOK

FOR THE

REGISTERING OF GAME SHOT, MEMORANDA OF SALE, &c.

By I. E. B. C.,

Editor of "Facts and Useful Hints relating to Fishing and Shooting," "The Gamekeeper's and Game Preserver's Account Book and Diary," &c.

Crown 8vo., price 2s. 6d., by post 2s. 9d.

PUBLIC SHOOTING QUARTERS

IN ENGLAND, WALES, SCOTLAND, IRELAND, AND ON THE CONTINENT.

By "WILDFOWLER,"

Author of "Shooting and Fishing Trips," "Modern Wildfowling," "Table of Loads," &c.

THIRD EDITION, ENLARGED AND REVISED.

Large post 8vo., with Illustrations, price 5s. cloth, by post 5s. 4d.

THE COUNTRY HOUSE:

A COLLECTION OF USEFUL INFORMATION AND RECIPES,

Adapted to the Country Gentleman and his household, and of the greatest utility to the housekeeper generally.

By I. E. B. C.,

Editor of "Facts and Useful Hints relating to Fishing and Shooting," and "The Gamekeeper's and Game Preserver's Account Book and Diary."

PUBLISHED ANNUALLY. *In post 8vo., price 1s. 6d., by post 1s. 8d.*

THE ANGLER'S DIARY

AND

TOURIST FISHERMAN'S GAZETTEER

CONTAINS

A Record of the Rivers and Lakes of the World, to which are added a List of Rivers of Great Britain, with their nearest Railway Stations.

Also Forms for Registering the Fish taken during the year; as well as the Time of the Close Seasons and Angling Licences.

By I. E. B. C.,

Editor of "The Gamekeeper's and Game Preserver's Account Book and Diary," &c.

THIRD EDITION. *In fcap. 8vo., price 1s., by post 1s. 1d.*

WILD BIRDS' PROTECTION ACT, 1880,

WITH COMMENTS ON THEIR RESPECTIVE SECTIONS

Explanatory of their bearing as regards owners and occupiers of land, sportsmen, bird catchers, bird dealers, &c.; together with Notes on the Birds named in the Schedule, their provincial names, &c.

An accurate exposition of and commentary on the recent measure, and will dispel many misconceptions of its scope."—*Quarterly Review.*

'A capital annotated edition of the Act."—*Saturday Review.*

"You have not the book of riddles about you, have you?"—*Merry Wives.*

Price 5s-, by post 5s. 3d.

"WHETSTONES FOR WITS;"

OR

DOUBLE ACROSTICS.

BY VARIOUS HANDS.

EDITED BY "CRACK."

"THE FIELD" OFFICE, 346, STRAND, W.C.

SECOND EDITIQN. *In demy 8vo., price 10s. 6d., by post 11s.*

ESTATE MANAGEMENT:

A PRACTICAL HANDBOOK FOR LANDLORDS, STEWARDS, AND PUPILS,

WITH A

LEGAL SUPPLEMENT BY A BARRISTER,

ALSO

Tenant Right from a Landlord's Point of View.

By CHARLES E. CURTIS.

CONTENTS:

In crown 8vo., price 1s., by post 1s. 1d.

CATECHISM OF ESTATE MANAGEMENT.

SECTION I.

LETTING AND LEASES.

BY

CHAS. E. CURTIS, F.S.I.,

Professor of Estate Management at the College of Agriculture, Principal of the School of Estate Management, Author of "Estate Management," &c.

In crown 8vo., with Thirteen full-page Plates, price 2s. 6d., by post 2s. 9d.

THE SWIMMING INSTRUCTOR:

A TREATISE ON THE ARTS OF SWIMMING AND DIVING.

By WILLIAM WILSON.

Author of "Swimming, Diving, and How to Save Life," "The Bather's Manual," "Hints on Swimming."

SECOND EDITION, Greatly Enlarged (with Illustrations and Plans of Silos).

Price 6s., by post 6s. 6d.

SILOS

FOR

PRESERVING BRITISH FODDER CROPS STORED IN A GREEN STATE.

Notes on the Ensilage of Grasses, Clovers, Vetches, &c.

COMPILED AND ANNOTATED

BY THE

SUB-EDITOR OF "THE FIELD."

CONTENTS.

Price 6d., by post 7d.

SHORT NOTES ON SILO EXPERIMENTS AND PRACTICE.

(Extracted from "Silos for Preserving British Fodder Crops.")

"THE FIELD" OFFICE, 346, STRAND, W.C.

Price 6d., by post 7d.

HARVESTING CROPS INDEPENDENTLY OF WEATHER:

Practical Notes on the Neilson System of Harvesting.

By "AGRICOLA,"
AND OTHER CONTRIBUTORS TO "THE FIELD."

In crown 8vo., price 2s. 6d., by post 2s. 8d.

MANURES:

THEIR RESPECTIVE MERITS FROM AN ECONOMICAL POINT OF VIEW.

BY A. W. CREWS,

Author of "Guano: its Origin, History, and Virtues," "The Potato and its Cultivation," &c.

CONTENTS.

PART. I.—Definition of the Word "Manure"—Nature's Modes of Applying Fertilisers—History—Classification.

PART II.—The Value of Ploughing Down Green Crops—Weeds—Sea-weed—Straw—Sawdust—Tanners' Bark—Wood Ashes—Peat—Rape Cake—Hemp—Poppy, Cotton, and Cocoa-nut Cakes—Bran—Malt Dust—Brewers' Grains—Coal—Soot—Charcoal.

PART III.—Dead Animals—Fish—Blood—Animalised Charcoal—Bones—Horn—Woollen Rags, Hairs, Feathers, &c.—Night-soil—Farmyard Manure—Guano.

PART IV.—Salts of Ammonia—Salts of Magnesia—Salts of Potash—Salts of Soda—Common Salt—Lime and its Compounds—"Ooze."

In crown 8vo., price 2s., by post 2s. 2d.

THE POTATO AND ITS CULTIVATION.

BY A. W. CREWS.

Author of "Guano: its Origin, History, and Virtues," "Manures: their Respective Merits, &c.

CONTENTS.

Derivation — History — Constituents — Varieties — Sprouting - Soils — Planting—Manures—Earthing up—Disease—Scab—Storing—Forcing—Producing New Varieties—Substitutes for the "Potato"—Miscellaneous Information.

PUBLISHED ANNUALLY. *Demy 4to., price 1s., by post 1s. 2d.*

THE RURAL ALMANAC

AND SPORTSMAN'S ILLUSTRATED CALENDAR FOR 1888.

Articles on the following Subjects are included in the List of Contents:

NOTES ON THE PAST RACING SEASON.
YACHT RACING IN 1887.
LIST OF HUNTS, THEIR MASTERS, &c.
FIELD TRIALS WITH POINTERS AND SETTERS IN 1887.
DOG SHOWS AND CANINE MATTERS IN 1887.
SUMMERING HUNTERS.
FOXHUNTING AND FARMERS.
COUNTY CRICKET IN 1887.
FISHERMEN'S COMFORTS.
BAITS AND BAIT CATCHING.
TENNIS SEASON OF 1887.
FLOWERS WORTH GROWING WELL.
VELOCITY OF THE FLIGHT OF BIRDS.
POULTRY IN LIMITED RUNS.
INVISIBLE APPROACH FOR WOOD PIGEONS AND OTHER BIRDS.
THE GOLFING GREENS OF THE WORLD.
TABLES OF AMATEUR AND PROFESSIONAL PEDESTRIAN, BICYCLING, AND SWIMMING PERFORMANCES, the best on Record.
STALLIONS FOR BREEDING BLOODSTOCK AND HUNTERS (List of about 300 Stallions, with their Pedigrees, and Fees for Thoroughbred and Half-Bred Mares).

ALSO SUMMARIES, TABLES, RECIPES, &c., VIZ.,

Angling close seasons
Athletic championships
Beagles, packs of
Bicycling, best times on record
Boat-races, Oxford and Cambridge
Boots, waterproofing and boning
Brown harness, dressing for
Cambridgeshire winners
Cesarewitch winners
Close seasons for game
Cricket on cocoa-nut matting
Derby winners
Dog clubs, list of
Fairs for horses, &c.
Foxhounds, packs of
Game, legal season for killing
Golfing greens of the British Isles
Harriers, packs of
Huntsmen, changes of
Jumping records
Lawn, improving the turf of
Oaks winners
Otter hounds, packs of
Public Schools athletics n 1887
Races of 1888, dates of
Racquets, Schools challenge cup
Running, best times
Stimulants for ferns
St. Leger winners
Swimming, amateur performances
Tennis, University matches
Terms, University and Legal
Tricycling performances
University athletic sports
University boat-races
University racquet matches
University tennis matches
Walking, best times.

In crown 8vo., price 5s., by post 5s. 4d.

BOAT-RACING;

OR,

THE ARTS OF ROWING AND TRAINING.

BY

EDWIN DAMPIER BRICKWOOD

(EX-AMATEUR CHAMPION OF THE THAMES).

CONTENTS.

PUBLISHED ANNUALLY. *Price 1s., by post 1s. 1d.*

THE ROWING ALMANACK AND OARSMAN'S COMPANION FOR 1887.

Edited by E. D. BRICKWOOD

(EX-AMATEUR CHAMPION OF THE THAMES),

Author of "Boat-Racing; or, the Arts of Rowing and Training."

CONTENTS.

"THE FIELD" OFFICE, 346, STRAND, W.C.

REPORTS on SALMON LADDERS, with Original Drawings, Plans, and Sections. By FRANCIS FRANCIS. In post 4to., price 2*s.* 6*d.*, by post 2*s.* 7*d.*

A MANUAL of the LAW of SALMON FISHERIES in ENGLAND and WALES, with a copious Index. By SPENCER WALPOLE, one of Her Majesty's Inspectors of Salmon Fisheries. Price 2*s.* 6*d.*, by post 2s. 8d.

A TABLE of CALCULATIONS for use with the "Field" Force Gauge for Testing Shot Guns. Also an Illustration and Description of the Apparatus. In demy 4to., price 2*s.* 6*d.*

THE RULES of PIGEON SHOOTING. Published by Special Permission, the Hurlingham Club and the Gun Club Rules of Pigeon Shooting. SECOND EDITION. Bound together in cloth, gilt edges, price 6d., by post 7*d.*

THE COURSING CALENDAR, for the Spring Season 1887, contains Returns of all the Public Courses run in Great Britain and Ireland. A revised List of Addresses of Coursing Secretaries, Public Coursers, Judges, Slippers, and Trainers, with List of Waterloo Cup Winners, Greyhound Sales, &c. Edited by C. M. BROWNE ("ROBIN HOOD"). Price 10*s.* 6*d.*

THE LAWS of LAWN TENNIS, as adopted by the Marylebone Cricket Club and the All England Croquet and Lawn Tennis Club. Entered at Stationers' Hall. Price 6*d.*, by post 6½*d.*

Price 6d., *by post* 7d.

ALL ENGLAND LAWN-TENNIS CLUB REGULATIONS for the MANAGEMENT of LAWN-TENNIS PRIZE MEETINGS, 1887.

Price 1*s.*, *by post* 1*s.* 3*d.*

THE "FIELD" LAWN TENNIS CALENDAR for 1887. Containing a List of Secretaries and their Addresses; Synopsis of the Laws of Lawn Tennis; Report of the Meeting of Representatives; and a Full Report of all the Meetings of the last Season, &c.

THE ITALIAN SYSTEM of BEE KEEPING; being an Exposition of Don Giotto Ulivi's Economical Frame Hives and Honey Extractor. By Arthur J. Danyell, late Capt. H.M. 31st Regiment. With Illustrations. Price 1*s.*, by post 1*s.* 1*d.* This pamphlet contains practical, directions for the making and utilisation of frame hives, costing less than 2*s.* each, and a centrifugal honey extractor costing 5*s.* or 6*s.*

In 4to., printed on toned paper, with plates, price 5s., by post 5s. 4d.

THE QUEEN LACE BOOK:

AN

Historical and Descriptive Account of the Hand-made Antique Laces of all Countries.

BY L. W.

This work contains the whole of the series of articles on Antique Point Lace which have been published in "The Queen." It will prove an invaluable guide and book of reference to ladies interested in Antique Lace, and, with its highly ornamental embossed cover, will form a handsome ornament for the drawing-room table.

ENGLISH TRANSLATIONS OF THE CLASSICS.

Post 8vo., 540 pages, price 7s. 6d.

HALF-HOURS WITH GREEK AND LATIN AUTHORS.

FROM VARIOUS ENGLISH TRANSLATIONS, WITH BIOGRAPHICAL NOTICES.

By G. H. JENNINGS and W. S. JOHNSTONE,

Authors of a "A Book of Parliamentary Anecdote."

In post 8vo., price 5s., by post 5s. 4d.

THE BARB AND THE BRIDLE:

A

HANDBOOK OF EQUITATION FOR LADIES,

AND

MANUAL OF INSTRUCTION IN THE SCIENCE OF RIDING FROM THE PREPARATORY SUPPLING EXERCISES ON FOOT TO THE FORM IN WHICH A LADY SHOULD RIDE TO HOUNDS.

By "VIEILLE MOUSTACHE."

Handsomely bound in cloth, price 3s. 6d., by post 3s. 9d.

ACTING CHARADES FOR OLD AND YOUNG.

BY

ARTHUR LILLIE

Author of "The Enchanted Toasting Fork," &c.

In paper cover, price 6d.

"THE QUEEN" RECIPES.

By "THE G. C." (Author of "Round the Table").