X. *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.

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INTRODUCTION.

In the experiments at Rothamsted with different manures, wheat has now been grown for 36 years in succession on the same land, barley for 28 years, and oats for nine years. Somewhat in like manner, but with some breaks, beans have been grown over a period of more than 30 years, clover for many years, and "root crops" (turnips, sugar-beet, or mangel-wurzel) also for more than 30 years. Each of these individual crops has exhibited certain distinctive characters under this unusual treatment. But, withal, those of the same natural family—wheat, barley, and oats, for example—have shown certain characters in common; those of the Leguminous family characters widely different; whilst the so-called root-crops, belonging to the Cruciferous and Chenopodiaceous families, have exhibited characteristics differing from those of either the Gramineæ or the Leguminosæ.

Compared with the conditions of growth of any one of these individual crops grown separately, those of the mixed herbage of grass land are obviously extremely complicated. Thus, it comprises, besides numerous genera and species of the gramineous and leguminous families, representatives also of many other natural orders, and of some of great prominence and importance as regards their prevalence and distribution in vegetation generally. And if, under the influence of characteristically different manuring agents, as has been the case, there have been observed notable differences in the degree of luxuriance of growth, and in the character of development, even between closely allied plants when each is grown separately, and much greater differences between the representatives of different families when so separately grown, might we not expect very remarkable variations of result when different manures are applied to an already established mixed herbage of perhaps some 50 species growing together, representing nearly as many genera, and more than 20 natural orders?

Such—far beyond what could have been anticipated—has been the case in the experiments to be described. So complicated, indeed, have been the manifestations of the "struggle" that has been set up, that even after more than 20 years of laborious experiment, both in the field and in the laboratory, and following up both the botany and the chemistry of the subject, we can hardly claim to have yet done much more than reach the threshold of a very comprehensive enquiry. Still, we hope to establish some points of general interest, and possibly to indicate promising paths of future research.

From the title of our paper, it will at once be concluded that the experiments were originally undertaken and arranged from an agricultural point of view. But, as experimenting on the feeding of animals soon led us into lines of enquiry of even more interest to the chemist, the animal physiologist, and the dietetician than to the agriculturist, so the investigation of the effects of different manures on the mixed herbage of grass land has led us far beyond the limits of a purely agricultural problem, and has afforded results of more interest to the botanist, the vegetable physiologist, and the chemist, than to the farmer. Indeed, agriculture—the most primitive, and commonly esteemed the rudest of the arts—requires for the elucidation of the principles involved in its various practices a very wide range of scientific enquiry; and the investigation of them may, in its turn, contribute facts of interest to the student of various and very distinct branches of natural knowledge.

It will be readily understood that, as a necessary foundation for the discussion of the botany and the chemistry of the subject, it will be essential first to put on record, and call attention to, what may be distinguished as the agricultural data. It is proposed, then, to arrange and consider the results obtained under the following heads:—

Part I.—The Agricultural Results.
Part II.—The Botanical Results.
Part III.—The Chemical Results.

It will facilitate the understanding of the very voluminous and very various experimental details which are to follow, if the scope of the enquiry, and the general character of the results, are somewhat further, but still only briefly, indicated in this place.

About seven acres in the Park at Rothamsted have been set apart for the experiments, and divided into plots. Two of these have been left without manure from the commencement; two have received ordinary farmyard manure; 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.

Referring first to the *agricultural results*, it may be premised that, *without manure*, the produce of hay has varied from year to year, according to season, from about 8 cwts. to nearly 39 cwts. per acre, and the average yield has been about 23 cwts. per acre per annum. On the other hand, the plot the most heavily artificially manured, and yielding the highest amount of produce, has given an average of about 64 cwts. of hay per acre per annum, with a variation from year to year from under 40 cwts. to nearly

80 cwts. Intermediate between the extremes here quoted, very great variation in the amount of produce has been exhibited on the other differently manured plots.

With these great differences in the amounts of produce the botanical character of the herbage has varied most strikingly. Thus, starting with perhaps 50 species on the unmanured land, any kind of manure—that is, anything that increases the growth of any species—induces a struggle, greater or less in degree, causing a greater or less diminution, or a disappearance, of some other species, until, on some plots, and in some seasons, less than 20 species have been observable; and on some, after a number of years, no more than this are ever traceable.

Even in the first years of the experiments, it was noticed that those manures which are the most effective with wheat, barley, or oats, grown on arable land—that is, with gramineous species grown separately—were also the most effective in bringing forward the grasses proper in the mixed herbage; and, again, those manures which were the most beneficial to beans or clover most developed the leguminous species of the mixed herbage, and *vice versâ*. It was further observed, that there was great variation in the predominance of individual species among the grasses, and also among the representatives of other orders. And even in the second year the differences in the flora, so to speak, were so marked that a first attempt at a botanical analysis of carefully taken samples of the produce of some of the plots was then made. In the third year more detailed separations were made; and, taking advantage of the experience thus gained, pretty complete botanical analyses have since been conducted four times, at intervals of five years, during the course of the now 24 years of the experiments; and on several other occasions partial separations have been undertaken. The character and tendency of the results so obtained may be very briefly indicated as follows:—

In the produce grown continuously without manure the average number of species found has been 49. Of these, 17 are grasses, 4 belong to the order Leguminosæ, and 28 to other orders. The percentage, by weight, of the grasses has averaged about 68, that of the Leguminosæ about 9, and that of species of other orders 23.

In the produce of the plot already referred to as the most heavily manured, and yielding the heaviest crops, the average number of species found has been only 19, of which 12–13 are grasses, 1 only (or none) leguminous, and 5–6 only represent other orders; whilst the average proportions by weight have been—of grasses about 95 per cent., of Leguminosæ less than 0·01 per cent., and of species representing other orders less than 5 per cent.

On the other hand, a plot receiving annually manures such as are of little avail for gramineous crops grown separately in rotation, but which favour beans or clover so grown, has given, on the average, 43 species. Of these, 17 in number are grasses, 4 Leguminosæ, and 22 belong to other orders; but, by weight, the percentage of grasses has averaged only 65–70, that of the Leguminosæ nearly 20, and that of species belonging to other orders less than 15.

With such very great variations, not only in the amount, but in the botanical character, of the produce of a crop under any circumstances so complex, it might be anticipated that there would be very great differences in its chemical composition, partly due directly to the supply of constituents by manure, partly to variation in the description of plants encouraged, and partly to the character and degree of development, and ripeness, of the varying components of the mixed herbage, according to the season and to the manure employed.

With a view to the elucidation of this part of the subject, the dry matter and the ash have been determined in the produce of every plot in every season; the nitrogen in that of all the plots for many of the seasons, and in some cases the amount of it existing as albuminoids has been determined. In selected cases, also, comparative determinations of "crude woody fibre" and of crude fatty matter have been made. About 120 complete ash-analyses have been executed. And, lastly, samples of the soil of every plot—in some cases at different periods, and in most cases representing the first, second, third, fourth, fifth, and sixth depths of nine inches, or, in all, to a total depth of 54 inches—have been collected, and these have been chemically examined in various ways.

It is found that there is a considerable difference in the percentage of dry substance in the produce, and very considerable difference in the percentage of mineral matter (ash) in that dry substance. There is still greater difference in the percentage of nitrogen in the dry matter, and, again, a greater difference still in the percentage of individual constituents of the ash. When, indeed, it is remembered that a plot may have from 20 to 50 different species growing upon it, each with its own peculiar habit of growth, and consequent varying range and power of food-collection, it will not appear surprising that different species are developed according to the manure employed; and, this being so, that the character and amount of the constituents taken up from the soil by such a *mixed herbage* should be found much more directly dependent on the supplies of them by manure than is the case with a crop of a single species growing separately.

In further illustration it may be mentioned that, not only does the percentage of nitrogen in the dry substance of the produce of the different plots vary considerably, but the average annual amount of it assimilated over a given area is more than three times as much in some cases as in others. Again, the percentage of potass in the dry substance is three times as much in some cases as in others; whilst the difference in the average annual amount of it taken up over a given area is more than five times as much on some plots as on others—dependent on the supplies of it by manure, and the consequent description of plants, and amount, and character, of growth induced. The percentage and acreage amounts of phosphoric acid also vary very strikingly; and so again it is with other mineral constituents, but in a less marked degree.

The foregoing summary statements will be sufficient to indicate the general scope, objects, and results, of the inquiry.

It will be seen that in the history of so many of what may be called natural rotations, we can hardly fail to learn not only much that is of interest in reference to the growth of the mixed herbage of permanent grass land, but also something of the relative positions of the different plants that are grown separately, in alternation with one another, in the artificial rotations adopted on arable land.

The botanical results are, moreover, of much independent interest, both by the facts which they already contribute, and by the incentive and direction they may give to future research.

Lastly, the chemistry of the subject will be found to offer many points of interest, in regard—to the variation in the percentage composition of the produce according to the manure applied, to the description of plants developed, and to the character of their development; to the availableness of the constituents artificially supplied, and to the amount and limit of the natural resources of the soil, both actually and compared with the results obtained when individual species are grown in arable culture.

It will be readily understood that the record, and the discussion, of the agricultural, the botanical, and the chemical history of about 20 plots, in 20 different seasons, must involve much detail; and although it is obvious that facts special to anyone of the three main divisions of the subject may require for their elucidation reference to those of one or both of the others, it is still believed that it will conduce to clearness, and reduce unavoidable repetition, to maintain the divisions proposed as far as possible. It may further be explained that, in order to simplify the discussion, and as far as is consistent with clearness to relieve it of embarrassing details, the whole of the numerical results are systematically arranged in tables given in the Appendix, to which reference will be made, and only such quotations or summaries will be embodied with the text as are necessary for illustration.

PART I.—THE AGRICULTURAL RESULTS.

In entering upon the discussion of the so-designated *agricultural* results, it is necessary to premise that almost from the commencement of the experiments it became apparent that more would be learnt, even of purely agricultural value, by continuing them in such manner as to obtain data bearing upon the important questions of the annual assimilation of constituents, the resources and the exhaustion of the soil, and the description of plants, and general characters of the herbage developed, under different conditions of season and of manuring, than by simply adapting the manures to obtain, as a direct result, produce which, considered either in regard to quantity, to quality, or to both, would be, in an economical sense, the most valuable. In fact, in some of the experiments conditions have been maintained which, though yielding very large amounts of produce, have done so not only at a great sacrifice of the quality of the hay, but at an entirely unremunerative cost; whilst, on the other hand, in some cases very high quality has been obtained, but again at far too high a pecuniary cost. In other words, the design of the arrangements has not been to secure results which should serve as direct models for practical agriculture, but such as should provide the data both for interesting scientific generalisation, and for useful practical deduction.

Accordingly, the present section of our report will be devoted mainly to a description of the influence of different manures, and of different seasons, on the amounts of produce obtained—that is, on the activity of accumulation and growth—with only such general references to the botanical, the chemical, or the economic character of the herbage, as may be necessary to prevent erroneous, and lead to correct interpretations and conclusions.

The experiments were commenced in 1856, so that the season of 1875 completed the twentieth, and the present season (1879) completes the twenty-fourth year of their continuance. They have been conducted on a portion of the Park at Rothamsted, where the land has probably been in grass for some centuries. No fresh seed has been artificially sown within the last 50 years certainly, nor is there record of any previous sowing. For many years prior to 1851 the plan was to manure occasionally with farm-yard dung, road scrapings, and the like; and in the later years sometimes with guano, or other purchased manures. One crop of hay was removed annually, averaging from $1\frac{1}{4}$ to $1\frac{3}{4}$ tons per acre. The second crop was always eaten off by sheep. In the spring of 1851, and again in 1852, four separate acres of the afterwards selected area were appropriated to the consumption by sheep of as many lots of differently-manured turnips, 10 tons of the roots being consumed upon each acre. Neither of these four acres was manured in any other way, nor was the remainder of the land manured at all in those two seasons (1851 and 1852), nor was any of it manured at all in either of the three next succeeding seasons—that is, in the three immediately preceding the commencement of the experiments in 1856. It may be added that the consumption of the different turnips on the land for two consecutive seasons did not in any case increase the produce over the five years, 1851–5 inclusive, by more than about 2 cwts. of hay per acre per annum. The land is a somewhat heavy loam, with red clay subsoil, resting upon chalk, and although it is not artificially, it is thus naturally, well drained. Lastly, the area selected is very level, and at the time the experiments were commenced the character of the herbage appeared fairly uniform over the whole of it.

At first, about five-and-a-half acres, divided into 13 plots, most of half, but some of a quarter of an acre each, were devoted to the purpose. In 1858 four more plots, comprising together two-thirds of an acre, were brought in; in 1865 one plot of half an acre; and in 1872 two plots of an eighth of an acre each; making, in all, about seven acres. Thus, the respective plots were commenced as follows:—

Plots 1–13 in 1856.
Plots 14–17 in 1858.
Plot 18 in 1865.
Plots 19 and 20 in 1872.

Two of the plots (3 and 12) have been left entirely unmanured from the commencement. One plot (1) received farmyard manure, with the addition of some ammonia-salts, for eight years in succession, since which time the application of the dung has been discontinued, and the ammonia-salts alone have been annually applied. One plot (2) received farmyard manure alone, each year, for eight years, and has since been left unmanured. The remaining plots have received, respectively, different descriptions or combinations of artificial or chemical manuring substances; the same, with some special exceptions, being applied year after year on the same plot. The most convenient forms in which the different constituents are supplied in commerce were selected. Thus, the different "mineral"* or ash-constituents were supplied in the substances designated in commerce as follows:—

Potass—as sulphate of potass (and in nitrate of potass).
Soda—as sulphate of soda (and in nitrate of soda).
Magnesia—as sulphate of magnesia.
Lime—as sulphate, 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 potass, soda, and magnesia, and in sulphate of ammonia.
Chlorine—in "muriate of ammonia."
Silica—as silicate of soda and silicate of lime (also in cut wheat straw).

Other constituents have been artificially supplied as under:—

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.

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 so prepared were sown broadcast by hand, as it has been found that the application of an exact amount of manure over a limited area of land can be best accomplished in that way.

During the first 19 years, the first crop only, each year, was mown, made into hay, removed from the land, and weighed; but in the twentieth season, 1875, a second crop was removed and weighed. As a rule, the second crop was fed off by sheep having no other food, the object being not to disturb the condition of the manuring. A given number was allotted to each plot, according to the amount of produce, and penned upon

* With regard to the use of the term "mineral," see 'Journal of the Royal Agricultural Society of England,' vol. xxiv., pp. 506–8 (foot-note); vol. xxv., p. 101 (and context); also vol. xvi., pp. 447–8 (and context).

a portion of it, the area being extended day by day, until the whole was eaten down. Frequently, however, the animals suffered so much, sometimes by the change of food, and sometimes by the combined influence of this and bad weather, that the plan was finally abandoned; and in the years 1866, 1870, 1873, and 1874, the second crops (and third if any) were mown, evenly spread on the respective plots, and left to decay and manure the land. The estimated amount of the second crops, and the influence of the treatment of them as above described, on the produce of the succeeding years, will be considered further on. But, in the first instance, our illustrations will chiefly have reference to the produce of hay of the first crops only.

A detailed description of the kinds and quantities of the manures applied to, and of the amounts of produce obtained from, each of the experimental plots, in each of the first twenty (and three subsequent) years, is given in Appendix–Table I., pp. 406–407. There is also given, in the same table, the average produce on each plot, over the first 10, the second 10, and the total period of 20 years, or over the period before, and the period after, any important change in the manures. It will, however, be convenient to give a general description of the manuring of each plot in this place.

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 4–1.—Sawdust (without effect), 3 years, 1856–58; superphosphate of lime,† 1859, and each year since.

Plot 4–2.—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 potass, soda, and magnesia, and superphosphate of lime, 1869, and each year since.

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

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

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

* "Ammonia-salts," in all cases equal parts, sulphate and muriate of ammonia of commerce.

† "Superphosphate of lime," always composed as under, per acre: 200 lbs. bone-ash, 150 lbs. sulphuric acid (sp. gr. 1·7), and water.

Plot 10.—Sulphates of potass, 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 potass) and superphosphate of lime (as plot 8), and ammonia-salts, 1862, and each year since ; also sawdust the first 7 years, but without effect.

Plot 11–1.—Sulphates of potass, 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 11–2.—The same as plot 11–1, with the addition of a mixture of silicate of lime and silicate of soda, 9 years, 1862–1870, and of silicate of soda only, 1871, and each year since.

Plot 12.—Unmanured, every year, 1856, and since.

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

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

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

Plot 16.—Sulphates of potass, 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 potass, 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 potass, containing the same quantity of potass as the nitrate of potass of plot 20, and superphosphate of lime, 1872, and each year since.

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

It will, perhaps, conduce to clearness of conception of the characteristic actions of the different descriptions of manure, if the results obtained are, in the first instance, discussed as far as possible without reference to the influence of the various seasons. Accordingly, it is proposed to consider the average amounts of produce yielded by characteristically different descriptions of manure, over the first 10, the second 10, and the total period of 20 years, of the continuous application to the same plot ; and, in the special cases in which the manure employed has been changed during the course of the experiments, to direct attention to the average produce obtained before and after such change.

As a preliminary to such a consideration of the effects of the different manures, it will be useful to call attention to the amounts of some of the most important constituents removed from a given area of land in a fair average hay-crop, compared with the amounts of the same removed in some other crops. For the purposes of such a comparison, wheat and barley may be selected, and we may assume the following amounts of produce per acre :—

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

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

Meadow hay, 1½ ton, or 3360 lbs.

The following table 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. As already indicated, and as will be very fully illustrated further on, meadow hay may vary so extremely in its botanical, and coincidently in its chemical composition, according to soil, climate, and manuring, that it is not possible to adopt an average composition for such produce with as much confidence as for either wheat or barley. This is well illustrated in the figures given in the four columns of the table relating to meadow hay. Assuming in each case the same weight, 1½ ton, of hay, we have the amounts of the several constituents calculated as follows :—In the first of the four columns according to the average composition, as determined by actual analysis, of the hay grown for eight years successively by farm yard manure ; in the second column according to the average composition of the hay grown during the same eight seasons without manure ; in the third column is given the mean of the two ; and in the fourth are given the amounts according to the average percentage of nitrogen adopted by E. WOLFF, and the average composition of the ash adopted by him, founded on the results of 39 analyses by various experimenters.

TABLE I.—Composition of average crops of Wheat, Barley, and Meadow Hay.

	In corn.		In straw.		In total produce.		1½ ton = 3360 lbs. meadow hay.			
	Wheat. (1800 lbs.)	Barley. (2080 lbs.)	Wheat. (3000 lbs.)	Barley. (2500 lbs.)	Wheat. (4800 lbs.)	Barley. (4500 lbs.)	8 years farmyard manure.	8 years without manure.	Mean.	Average E. WOLFF.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
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
Potass . . .	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

As, in the ordinary practice of rotation on arable land, most of the constituents of the straw of wheat and barley, which are in the first instance removed from it, are in due course returned to it, the eventual loss of constituents to the land by the growth of such crops will be more nearly represented by the amounts in the grain alone, than by those in the total produce, corn and straw together. In the case of the hay crop the return of constituents is by no means so regular, and the figures show how very variable may be the amount of them in a given weight of the crop, according to the supply of them in the soil, or by manure. Thus, whilst there is more nitrogen in a given weight of the hay grown without manure than with farmyard manure, there is one-and-a-half time as much phosphoric acid, and more than one-and-three-quarters time as much potass, in the hay grown by farmyard manure than in that without manure. On the other hand, there is more lime, more magnesia, much more soda, and more sulphuric acid, but less silica, and much less chlorine, in a given weight of the unmanured than of the manured produce. In spite of these variations the mean of the two gives a composition agreeing very fairly in essential points with the average deduced by E. WOLFF from the results of 39 ash-analyses by different experimenters.

Assuming as the basis of comparison the mean composition of the manured and the unmanured hay, it is seen that a fairly good crop 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 potass, 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, corn 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 corn and straw together. Of phosphoric acid and silica alone, will the total produce of the corn crops remove more than the hay crop.

To sum up the most important points: it is quite obvious that, in the soil in question, which it should be remembered is a loam with a clay subsoil, the effect of the application of a complex manure such as dung, 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 potass; notably also that of phosphoric acid, and to some degree that of silica; much more chlorine was also taken up. In fact, as will be shown further on, the supply by manure of potass has a more marked effect on the quantity, and on the botanical and the chemical character, of the herbage of the hay crop, than that of any other of the mineral, or ash-constituents. If these few illustrations relating to the composition of the crop be borne in mind, the results relating to the effects of different manures upon it will be the more easily understood.

The next point to be considered is the effects of certain characteristically different conditions as to manuring, each, respectively, continued for many years in succession on the same plot.

1. *Without Manure; Plots* 3 *and* 12.

The following table shows the average produce of hay obtained, per acre per annum, without any manure, over the first 10 years, the second 10 years, and the total period of 20 years, from 1856 to 1875 inclusive; also the amounts of nitrogen, and mineral matter (ash), which the hay contained.

TABLE II.—Average, per acre per annum, without Manure.

	Average per acre per annum.		
	Plot 3.	Plot 12.	Mean.
HAY.			
	lbs.	lbs.	lbs.
First period, 10 years, 1856–1865	2531	2808	2670
Second period, 10 years, 1866–1875	2236	2564	2400
Total period, 20 years, 1856–1875	2383	2686	2535
Second period, per cent. + or − first period	−11·7	−8·7	−10·1
NITROGEN.			
First period, 10 years, 1856–1865	35·1	39·3	37·2
Second period, 10 years, 1866–1875	30·9	35·6	33·3
Total period, 20 years, 1856–1875	33·0	37·5	35·3
Second period, per cent. + or − first period	−12·0	−9·4	−10·5
MINERAL MATTER (ASH).			
First period, 10 years, 1856–1865	148·5	161·7	155·1
Second period, 10 years, 1866–1875	126·1	143·2	134·6
Total period, 20 years, 1856–1875	137·3	152·4	144·9
Second period, per cent. + or − first period	−15·1	−11·4	−13·2

It will be seen that, over both periods, one of the unmanured plots (12) yielded more produce of hay than the other (3). It also yielded more nitrogen, and more mineral matter, whilst, in all three particulars—hay, nitrogen, and mineral matter—its decline in yield over the second period compared with the first was less. For a long time the proper explanation of this superiority was not very obvious; but it was supposed to be due, in part at least, to the fact that plot 12 is earlier sheltered from the evening sun, and therefore the less liable to suffer in dry weather. After the experiments had been continued for 20 years, however, the soil of each of the plots was sampled, in three places, in each case six depths of nine inches, or in all a total depth of 54 inches, being taken; and both the notes made on the sections of the soil and subsoil, and the percentages of nitrogen at the respective depths (determined by the soda lime method), lead to the conclusion that a considerable part, at any rate, of plot 12 must have been made ground, as the mould extended to a greater depth, and, as will be seen further on, the percentage of nitrogen in the lower layers was considerably higher than in the case of the other unmanured plot, and indeed higher than in that of most of the manured plots. After a careful consideration of the facts, it has been decided that the results obtained on plot 3 provide fairer standards with which to compare those yielded on the manured plots than would the mean indications of the two unmanured plots. Accordingly, all such comparisons, unless otherwise stated, have reference to the produce of the unmanured plot 3.

The average annual decline in yield on plot 3, over the second 10 years compared with the first, amounted to nearly 300 lbs. of hay, to rather more than 4 lbs. of nitrogen, and to about $22\frac{1}{2}$ lbs. of total mineral matter. The percentage decline over the second period was slightly greater in the nitrogen than in the hay, and greater in the mineral matter than in either. The analytical results will show that the deficiency was more or less in all of the mineral constituents; but it was the more marked in the cases of the potass and the soda, the phosphoric and the sulphuric acids, and especially of the silica.

It may be concluded that, apart from the influences of season, which were not without effect on the result, the reduction of produce on the continuous growth without manure was due, in part to deficiency of available nitrogen, but probably more still to that of an available supply of potass, of phosphoric acid, and of silica.

Under these conditions of general want of luxuriance—of no marked predominance of either nitrogen or any special mineral constituent, favouring any particular species or families of plants—no artificial struggle was set up. The result was a more complex herbage than on any of the manured plots. In other words, a greater number of species maintained a place. The proportion of the produce consisting of gramineous herbage was comparatively low; that of the leguminous was fairly high; but the most marked characteristic was the large number, and high proportion by weight, of the miscellaneous species.

Under the influence of such great variety in the character and habit of growth of the plants composing the unmanured mixed herbage, accompanied it may be supposed with correspondingly varied powers of food-collection, we have a considerably greater annual assimilation of nitrogen, and of some of the most important mineral constituents, over a given area, than in an unmanured gramineous crop grown separately, on arable land, such as wheat or barley for example. The characteristic differences in the percentage composition of the different kinds of herbage, and in the amounts of constituents they respectively take up, will be further illustrated as we proceed.

2. *Ammonia-Salts alone; Plot* 5.

Over the same periods of 10 years, 10 years, and 20 years, the following results were obtained by the annual application of ammonia-salts alone, at the rate of 400 lbs. per acre per annum, estimated to supply about 100 lbs. of ammonia, corresponding to about 82 lbs. of nitrogen; and, for comparison, the results obtained on plot 3, without manure, are also given.

TABLE III.—Average, per acre per annum, by 400 lbs. 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.			
	lbs.	lbs.	lbs.
First period, 10 years, 1856–1865	2531	3420	+889
Second period, 10 years, 1866–1875	2236	2471	+235
Total period, 20 years, 1856–1875	2383	2946	+563
Second period, per cent. + or − first period	−11·7	−27·7	
NITROGEN.			
First period, 10 years, 1856–1865	35·1	57·9	+22·8
Second period, 10 years, 1866–1875	30·9	47·3	+16·4
Total period, 20 years, 1856–1875	33·0	52·6	+19·6
Second period, per cent. + or − first period	−12·0	−18·3	
MINERAL MATTER (ASH).			
First period, 10 years, 1856–1865	148·5	181·2	+32·7
Second period, 10 years, 1866–1875	126·1	108·9	−17·2
Total period, 20 years, 1856–1875	137·3	145·1	+ 7·8
Second period, per cent. + or − first period	−15·1	−39·9	

Compared with the produce without manure, ammonia-salts alone have given an average annual increase over 20 years of 563 lbs. of hay, or, in all, of 11,260 lbs., or rather more than 5 tons; and it is to be observed that the increased growth was dependent for the necessary mineral constituents (sulphuric acid and chlorine only excepted) on the supplies of the soil exclusively. But, whilst the average annual increase was 889 lbs. over the first 10 years, it was only 235 lbs. over the second

10 years. The falling off of effect is, therefore, very great; and the proportional reduction of produce is more than twice as great as without manure. There is also a considerable reduction in the yield of nitrogen per acre; but as the amount annually supplied in the manure was several times greater than the increase of nitrogen in the crop by its use, and the percentage of nitrogen in the produce was abnormally high, the deficiency of growth was obviously not dependent on a want of nitrogen. The reduction in the yield of mineral matter, on the other hand, is seen to be nearly 40 per cent. over the second compared with the first 10 years.

Leaving out of consideration the amounts of sulphuric acid and chlorine taken up, these being largely supplied in the ammonia-salts, there was, of all the mineral constituents derived from the soil itself, more taken up during the first 10 years under the influence of the ammonia-salts than without manure. Of lime, of potass, and of silica there was, however, considerably less taken up over the second 10 years than without manure; of lime and of potass so much less that of these there was actually less yielded up by the soil in the 20 years with the ammonia-salts than without manure. Of magnesia, and of phosphoric acid, there was, on the other hand, rather more yielded up over both periods with the ammonia-salts than without it. Of lime, of potass, and of silica, indeed, the percentage in the dry substance of the produce of the ammonia plot was abnormally low.

That there should be actually less lime and potass taken up with the ammonia than without manure is probably to be explained by 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 been displaced. Under the influence of the ammonia-salts the total number of species found was greatly reduced; the herbage became more and more gramineous; *Festuca ovina* sometimes yielded more than half, and *Agrostis vulgaris* more than a quarter of the total produce; there was scarcely any leguminous herbage; and of miscellaneous species there were but few in number, which contributed but a small proportion of the weight, excepting *Rumex acetosa*, which was objectionably flourishing. Thus, the produce consisted chiefly of the poorer grasses, which, moreover, showed very little tendency to form stem and seed, whilst 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.

The next illustrations also show the effects of a continuous supply of nitrogenous without mineral manures.

3. *Nitrate of Soda alone; Plots* 15 *and* 17.

Plot 15 received, for 18 years in succession, approximately the same amount of nitrogen per acre per annum as plot 5, but as nitrate of soda instead of as ammonia-salts; and plot 17 has received annually half the quantity of nitrate. The experiments with the nitrate commenced two years later than most of the others; and that on plot 15 ended in 1875; whilst that on plot 17, like that on plot 5 with the ammonia-salts, has been continued up to the present time. The average produce of hay, &c., cannot, therefore, be taken over precisely the same, or as many years, with the nitrate as with the ammonia-salts.

The following table shows the average results obtained over the first 8, the next 10, and the total period of 18 years, of the application of the nitrate on plot 15; also those obtained, over the same periods, on plot 17, with only half the quantity of nitrate. For comparison, there are also given the results yielded, over the same periods, on plot 3 without manure, and on plot 5 with the ammonia-salts.

TABLE IV.—Average, per acre per annum, by 550 lbs. and 275 lbs. Nitrate of Soda alone; Plots 15 and 17.

	Average per acre per annum.								
	Plot 3. Without manure.	Plot 5. 400 lbs. ammonia-salts.	Plot 15. 550 lbs. nitrate soda.	Plot 17. 275 lbs. nitrate soda.	Plot 15. + or − plot 3.	Plot 15. + or − plot 5.	Plot 17. + or − plot 3.	Plot 17. + or − plot 5.	Plot 17. + or − plot 15.
HAY.									
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
First period, 8 years, 1858-1865 . . .	2492	3300	4038	3837	+1546	+ 738	+1345	+ 537	−201
Second period, 10 years, 1866-1875 . .	2236	2471	3913	3755	+1677	+1442	+1519	+1284	−158
Total period, 18 years, 1858-1875 . .	2350	2839	3968	3792	+1618	+1129	+1442	+ 953	−176
Second period, per cent. + or − first period	−10·3	−25·1	−3·1	−2·1					
NITROGEN.									
First period, 8 years, 1858-1865 . . .	33·9	57·2	63·1	55·5	+29·2	+ 5·9	+21·6	−1·7	−7·6
Second period, 10 years, 1866-1875 . .	30·9	47·3	61·5	53·2	+30·6	+14·2	+22·3	+5·9	−8·3
Total period, 18 years, 1858-1875 . .	32·2	51·7	62·2	54·2	+30·0	+10·5	+22·0	+2·5	−8·0
Second period, per cent. + or − first period	−8·9	−17·3	−2·5	−4·1					
MINERAL MATTER (ASH).									
First period, 8 years, 1858-1865 . . .	145·8	168·2	225·9	223·8	+80·1	+57·7	+78·0	+55·6	−2·1
Second period, 10 years, 1866-1875 . .	126·1	108·9	205·4	205·0	+79·3	+96·5	+78·9	+96·1	−0·4
Total period, 18 years, 1858-1875 . .	134·9	135·3	214·5	213·3	+79·6	+79·2	+78·4	+78·0	−1·2
Second period, per cent. + or − first period	−13·5	−35·3	−9·1	−8·4					

As the experiments with the nitrate commenced two years later than those without manure and those with ammonia-salts, the results are, so far, not strictly comparable; but a careful consideration of them shows that, if the exact figures cannot, the main indications can, without doubt, be thoroughly relied upon.

We will first refer to the results on plot 15, receiving 550 lbs. of nitrate of soda per acre per annum, estimated to contain the same amount of nitrogen as the 400 lbs. ammonia-salts applied to plot 5, namely, 82 lbs. It is remarkable that, whilst with a given amount of nitrogen applied as ammonia-salts there was an average annual increase of produce over the 18 years of only 489 lbs., there was with the same amount applied as nitrate of soda 1618 lbs., or 1129 lbs. more. Or, to put it in another way, whilst the ammonia-salts gave an average annual increase of little more than one-fifth over the unmanured produce, the nitrate of soda gave more than one-and-two-thirds as much. Further, whilst over the second period compared with the first the produce declined 10·3 per cent. without manure, and 25·1 per cent. with ammonia-salts, it only fell off 3·1 per cent. with the nitrate of soda.

The yield of nitrogen, again, was one-fifth more under the influence of the nitrate than of the ammonia-salts; and whilst, over the second period compared with the first, it declined nearly 9 per cent. without manure, and more than 17 per cent. with ammonia-salts, the reduction was only 2½ per cent. with the nitrate of soda.

But it was in the amounts of mineral matter taken up that the difference in the effects of the ammonia-salts and the nitrate of soda was the most marked. Thus, whilst over the 18 years the quantities of mineral matter removed in the crops were almost identical without manure and with ammonia-salts, with the nitrate of soda more than one-and-a-half time as much was taken up; and the increase, which amounted to an average of nearly 80 lbs. per acre per annum, was more than two-and-a-half times as much as is accounted for by the increased amount of soda taken up, due to the nitrate of soda used. It is remarkable, too, that whilst the decline in the amount of mineral matter taken up over the second period compared with the first was 13·5 per cent. without manure, and 35·3 per cent. with the ammonia-salts, it was only 9·1 per cent. with the nitrate of soda. Of individual mineral constituents, not supplied in either manure, more lime, more magnesia, and considerably more of potass, phosphoric acid, and silica, were removed in the produce by the nitrate than in that by the ammonia-salts.

To attempt to explain these results, even as fully as the data at command will allow, would be to go beyond the facts more special to this section, and to trench upon those specially belonging to the botanical and chemical sections, and would, indeed, involve a long discussion. It must suffice in this place briefly to indicate the main points. Under the influence of the nitrate of soda a greater total number of species maintained a place than under that of the ammonia-salts. Among the grasses a greater variety contributed to the bulk of the herbage, and they showed a greater tendency to form stem and seed. There was also somewhat more leguminous herbage, and considerably more referable to miscellaneous species, of which, moreover, a greater number were fairly prominent.

It will be readily conceived that, under the conditions here described, there would be a greater variety, and better development, and consequently a wider and deeper distribution of the roots of the collective mixed herbage growing under the influence of the nitrate, giving it a command of the stores of a correspondingly increased range of soil and subsoil. Again, it is well known that (in whatever combination it does so in either case) the nitrogen of nitrate of soda distributes much more rapidly, not only in the upper but also in the lower layers of the soil, than does that of the ammonia-salts. Direct observation has further shown that, with this, there is a greater development of some of the deeper rooting species, and consequently a greater distribution of roots in the lower layers. Thus, the mixed herbage growing under the influence of the nitrate draws more upon the deeper layers; it has, therefore, a greater supply of mineral constituents at its disposal; and hence, though taking more from the soil itself, it shows exhaustion much more tardily. How much the action of the nitrate of soda, or of its products of decomposition, in liberating or rendering available otherwise locked up constituents of the soil and subsoil, may have contributed to the result is obviously a question worthy of consideration.

The results of plot 17 show the effects of nitrate of soda applied in quantity supplying only half as much nitrogen as that of the ammonia-salts of plot 5, or of the nitrate of soda of plot 15.

The figures show much more produce and increase over the first, second, and total periods, by the use of nitrate of soda in this smaller quantity, than by that of ammonia-salts containing twice as much nitrogen; indeed, there was, over the first period only 201 lbs., over the second only 158 lbs., and over the total period only 176 lbs., less hay per acre per annum, than was obtained by double the amount of nitrate of soda. Further, the yield is only 2 per cent. less over the second period compared with the first.

Of nitrogen in the produce, the smaller quantity of nitrate of soda gave somewhat less over the first period, but considerably more over the second, and more over the total period, than twice the quantity applied as ammonia-salts; and there was, at the same time, comparatively little decline in yield over the second period compared with the first. There was, however, an average of about 8 lbs. per acre per annum less nitrogen in the produce by the smaller than in that by the double amount of nitrate of soda; but there was, nevertheless, a much larger proportion of that supplied recovered in the increase of crop where the smaller quantity was used.

It has been seen how strikingly greater was the amount of mineral matter taken up under the influence of a quantity of nitrate containing the same amount of nitrogen as the ammonia salts; and it is even more remarkable that here, with only half the quantity of nitrate, there is, over the whole period, within about 1 lb. per acre per annum as much mineral matter removed in the crop as with the double quantity, whilst the falling off in amount over the second period is even rather less. There was, indeed, even more lime, more potass, and more silica, taken from the soil in the crops grown by the smaller than in those by the larger amount of nitrate, and at the same time nearly as much magnesia and phosphoric acid. The deficiency was mainly due to much less soda being taken up.

In reference to the striking effects of this smaller quantity of nitrate of soda alone, over a period of 18 years, during which, excepting in the item of soda, the growth was entirely dependent for mineral constituents on the supplies of the soil itself, it may be remarked that the same circumstances which were pointed out as serving to explain the better result with the larger amount of nitrate than with the ammonia-salts, obtained in even a rather greater degree where the smaller quantity of nitrate was used. Thus, a still greater total number of species grew; a somewhat greater number of the grasses contributed to the bulk of the gramineous herbage; the tendency to form stem and seed was greater; the proportion in the produce of the non-gramineous herbage was greater, and it was made up of a greater variety of species. It is to be supposed, therefore, that the roots would have more complete possession of the soil and the higher layers of the subsoil. It has been seen, indeed, that they had sufficient command of them to take up nearly as much total mineral matter, and even rather more of the important constituents—lime, potass, and silica—than with the larger amount of nitrate.

It would appear that the limit of growth under the influence of nitrate of soda alone—that is to say without the aid of any artificial supply of mineral constituents —was nearly reached with the smaller quantity used; and a comparison of the results obtained by it with those by the double quantity led us to stop the application of this after the twentieth year of the experiments, that is to say, after 18 years of its use. A mixed mineral manure, comprising sulphates of potass, soda, and magnesia, and superphosphate of lime, has now been applied instead for four years, and it is proposed to continue the application with a view to determine what proportion, if any, of the hitherto unrecovered nitrogen of the excess of nitrate supplied will be recovered, and also to observe the changes in the flora, so to speak, under this change of treatment. So far, the indications are not in favour of the supposition that any material proportion of the previously unrecovered nitrogen of the nitrate will be recovered in subsequent crops; indeed, it would appear probable that much has passed away by drainage. The general character of the herbage, is, however, rapidly changing. The grasses show a much lighter colour, and much more tendency to form stem, and to mature; leguminous species (especially *Lathyrus pratensis*) are gaining ground; and the character of the miscellaneous herbage is also changing.

4. *Mixed Mineral Manure alone; Plot* 7.

We have now to show the effects of a mixed mineral manure, such as just referred to, when applied to the complex herbage year after year without any nitrogenous manure. This experiment was commenced in the first year of the series, 1856, and has been continued up to the present time.

The "mixed mineral manure" used, was composed, per acre per annum, as follows:—

300 lbs. sulphate of potass.
100 lbs. sulphate of soda (200 lbs. the first 8 years).
100 lbs. sulphate of magnesia.
200 lbs. bone ash } superphosphate of lime.
150 lbs. sulphuric acid, sp. gr. 1·7 }

The following table shows the results obtained over the first 10, the second 10, and the total period of 20 years, 1856–75 inclusive, also, for comparison, those without manure over the same periods.

TABLE V.—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.			
	lbs.	lbs.	lbs.
First period, 10 years, 1856–1865	2531	3797	+1266
Second period, 10 years, 1866–1875	2236	4118	+1882
Total period, 20 years, 1856–1875	2383	3958	+1575
Second period, per cent. + or − first period . . .	−11·7	+8·5	
NITROGEN.			
First period, 10 years, 1856–1865	35·1	55·2	+20·1
Second period, 10 years, 1866–1875	30·9	58·0	+27·1
Total period, 20 years, 1856–1875	33·0	56·6	+23·6
Second period, per cent. + or − first period . . .	−12·0	+5·1	
MINERAL MATTER (ASH).			
First period, 10 years, 1856–1865	148·5	246·3	+ 97·8
Second period, 10 years, 1866–1875	126·1	261·6	+135·5
Total period, 20 years, 1856–1875	137·3	254·0	+116·7
Second period, per cent. + or − first period . . .	−15·1	+6·3	

Here then, with a *mixed mineral manure alone*, we have considerably higher amounts of produce than with nitrogenous manure alone applied as ammonia-salts, and, taking the whole period, nearly as much as when applied as nitrate of soda. Not only so, instead of a reduction in hay, in nitrogen, and in mineral matter, removed over the second compared with the first 10 years, there is an increase of all three over the second period.

It is, nevertheless, sufficiently established that nitrogenous manures are specially effective in increasing the growth of gramineous crops grown separately on arable land, such as wheat, barley, or oats, all of which contain a comparatively small percentage of nitrogen, and assimilate a comparatively small amount of it over a given area when 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 soil and seasons, mineral manures alone increase comparatively little the gramineous crops grown separately, such manures, and especially potass manures, do in a striking degree increase the growth of crops of the leguminous family so grown, and coincidently increase the amount of nitrogen they assimilate over a given area.

Consistently with this, as will be fully illustrated in the proper place, the application to the mixed herbage of the mineral manure, containing potass, as above described, did very considerably increase the growth of leguminous species. But, more or less from the beginning, and especially in the later seasons, it increased that of some gramineous species very much also—indeed, much more than our experience in the growth of gramineous crops by mineral manures on arable land led us to anticipate.

Table VI. gives approximate estimates of the average amounts, per acre per annum, of hay, nitrogen, and mineral matter, referable respectively to gramineous, leguminous, and miscellaneous species, in the produce of plot 3 without manure, and of plot 7 with the mixed mineral manure, over the first 10, the second 10, and the 20 years. As the botanical separations were not made so frequently in the earlier as in the later years, and as the determinations of nitrogen and mineral matter, and of the composition of the ash, in the separated gramineous, leguminous, and miscellaneous herbage, have only been made in recent years, the estimates are obviously only approximate; but they are doubtless sufficiently near the truth to bring clearly to view the characteristic distinctions between the produce of the two plots, and therefore to afford important data for judging of the effects of the manure. The following are the mean percentages of nitrogen, and of mineral matter, in the different descriptions of herbage, as adopted in the calculations, in each case reckoned on the herbage in the condition of dryness of hay :—

	Gramineous herbage.		Leguminous herbage.		Miscellaneous herbage.	
	Plot 3.	Plot 7.	Plot 3.	Plot 7.	Plot 3.	Plot 7.
Per cent. nitrogen	1·25	1·18	2·31	2·31	1·45	1·32
Per cent. mineral matter (ash) . . .	5·11	5·64	6·32	6·81	7·30	8·74

TABLE VI.—Hay, Nitrogen, and Mineral Matter, referable to Gramineous, Leguminous, and Miscellaneous Herbage respectively, without Manure, and by "Mixed Mineral Manure;" Plots 3 and 7.

	Average per acre per annum.								
	Gramineous herbage.			Leguminous herbage.			Miscellaneous herbage.		
	Plot 3. Without manure.	Plot 7. Mineral manure.	Plot 7. + or − plot 3.	Plot 3. Without manure.	Plot 7. Mineral manure.	Plot 7. + or − plot 3.	Plot 3. Without manure.	Plot 7. Mineral manure.	Plot 7. + or − plot 3.
HAY.									
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
First period, 10 years, 1856–1865	1668	2324	+ 656	186	754	+568	677	719	+ 42
Second period, 10 years, 1866–1875	1523	2643	+1120	178	813	+635	535	662	+127
Total period, 20 years, 1856–1875	1596	2484	+ 888	182	784	+602	606	691	+ 85
Second period, per cent. + or − first period	−8·7	+13·7		−4·3	+7·8		−21·0	−7·9	
NITROGEN.									
First period, 10 years, 1856–1865	20·9	27·8	+ 6·9	4·3	17·7	+13·4	9·9	9·7	−0·2
Second period, 10 years, 1866–1875	19·1	30·8	+11·7	4·1	18·6	+14·5	7·7	8·6	+0·9
Total period, 20 years, 1856–1875	20·0	29·3	+ 9·3	4·2	18·2	+14·0	8·8	9·1	+0·3
Second period, per cent. + or − first period	−8·6	+10·8		−4·7	+5·1		−22·2	−11·3	
MINERAL MATTER (ASH).									
First period, 10 years, 1856–1865	86·6	131·7	+45·1	11·9	51·5	+39·6	50·0	63·1	+13·1
Second period, 10 years, 1866–1875	76·7	148·7	+72·0	11·1	55·1	+44·0	38·3	57·8	+19·5
Total period, 20 years, 1856–1875	81·6	140·2	+58·6	11·5	53·4	+41·9	44·2	60·4	+16·2
Second period, per cent. + or − first period	−11·4	+12·9		−6·7	+7·0		−23·4	−8·4	

It is seen that, over the 20 years, more than one-and-a-half time as much gramineous herbage was grown by the purely mineral manure as without manure; and that, whilst without manure there was a decline in the second 10 years compared with the first, there was with the mineral manure a considerable increase over the later period.

Of leguminous herbage there was not nearly so much actual increase of weight by the mineral manure as there was of the gramineous; but the proportional increase was much greater, there being more than four times as much grown with the mineral manure as without manure, and there was also more over the second period than over the first.

Of miscellaneous herbage there was very little increase by the manure, and a falling off in actual amount over the later years.

The facts relating to the nitrogen bring out more strikingly the characteristic effects of the mixed mineral manure in favouring the development of leguminous species. The figures given on page 309 show that whilst the percentage of nitrogen in the miscellaneous herbage is not much higher than that in the gramineous, the percentage in the leguminous herbage is very much higher; in fact, not far from twice as high. The result is that, although there is by the mineral manure a greater increase in gramineous than in leguminous hay, a larger proportion of the increase of nitrogen is due to the leguminous than to the gramineous herbage; whilst the miscellaneous herbage contributes practically none of the increased yield of nitrogen. Again, whilst in the unmanured produce the leguminous herbage has taken up little more than one-fifth as much nitrogen as the gramineous, in the mineral manured produce there is nearly two-thirds as much in the leguminous as in the gramineous herbage. Or, to put it in another way, whilst the average annual amount of nitrogen in the gramineous herbage was 20 lbs. without, and 29·3 with, the manure, or 9·3 lbs. more with than without it, it was in the leguminous herbage only 4·2 lbs. without, but 18·2 lbs. with the manure, or 14·0 lbs. more with than without it.

As already said, it is entirely consistent with experience in the growth of individual leguminous crops on arable land, that the amount, both of the produce and of the nitrogen assimilated, should be considerably increased under the influence of such a manure; and although the source of the increased yield of nitrogen under such circumstances is not conclusively proved, the weight of evidence is in favour of the conclusion that it is derived from the soil; and, in the case of clover and beans, at any rate, more probably from the lower than the upper layers. In the unmanured mixed herbage the deeper-rooting *Lotus corniculatus* and *Trifolium pratense* contributed most of the leguminous produce; but in the manured herbage it is the comparatively surface-rooting *Lathyrus pratensis* that mainly contributes the leguminous increase.

Again, although experience in the growth of gramineous crops on arable land did not lead us to expect so much increase in the growth of gramineous species in the mixed herbage, yet even among the grain crops there is a notable difference in the effect of mineral manures, according to the habit of development of the plant, and to the circumstances of its growth. Thus, the 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 amount of fibre near the surface, and is more benefited by the application 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. In accordance with this, the greatly increased yield of gramineous produce 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*, *Agrostis vulgaris*, and *Holcus lanatus*.

The question still remains—what is the source of the greatly increased yield of nitrogen, both in the gramineous and the leguminous herbage, under the influence of the purely mineral, that is non-nitrogenous, manure?

The annual yield of nitrogen per acre, in the gramineous herbage alone, of the unmanured plot, is approximately the same as that obtained in wheat or barley grown on arable land of somewhat similar character for many years in succession; and the leguminous and miscellaneous herbage together contribute about two-thirds as much; making, therefore, in all a much greater total annual yield in the mixed herbage than in the cereal crop. That it should be greater, at any rate for a considerable period of time, would seem only natural to expect, when it is borne in mind that the surface-soil of permanent meadow land is much richer in nitrogen, due to vegetable débris and previous accumulations, than arable land of otherwise corresponding character; and, further, that many of the components of the mixed herbage have possession of the soil, and are more or less growing, almost the year round. But, under the influence of the mineral manure, the total yield of nitrogen per acre per annum averaged one-and-two-thirds as much as without manure, and about two-and-a-half times as much as would be yielded in a cereal crop similarly manured on arable land; and, without direct evidence on the point, it would hardly be concluded that this largely increased yield could be accounted for in a similar way to that of the lesser amount without manure.

In seeking for an explanation, it had to be borne in mind, that such mineral manures did also considerably increase the growth of leguminous crops grown on arable land; and, further, that when a leguminous crop is grown on arable land it not only removes much more nitrogen from a given area than a gramineous one grown under equal conditions as to soil and season, but it leaves the upper layers of the soil so much richer in nitrogen, and in such condition that the increase may be determined by the soda-lime method, and the growth of the succeeding cereal is considerably augmented. The question, therefore, suggested itself—how far the increased growth of the grasses proper in the mixed herbage was due to 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? Whether, in fact, where the plants are thus growing in association, there is a parallel action to that which takes place when they are grown in alternation?

This explanation obviously itself left unsolved the question of the source of the nitrogen of the Leguminosæ, besides involving other difficulties. Still, it seemed to accord with other known facts, and to be at any rate the best that could be offered in defect of more satisfactory or countervailing evidence. However, as already referred to, after the experiments had been continued for 20 years, samples of the soils and subsoils were taken, from each plot, at different depths, and determinations of nitrogen have been made in them. The results show a considerably lower percentage in the first nine inches of depth of the mineral manured plot 7 than in that of the unmanured plot 3; and so far as the calculation of such results into quantities per acre can be relied upon, the difference is more than sufficient to account for the increased yield of nitrogen over the 20 years in both the gramineous and the leguminous herbage of plot 7. The details will be fully considered further on. But, in the meantime, a clue to the source of the increased yield of nitrogen in the mixed herbage would seem to be obtained. It would appear that, under the influence of the mixed mineral manure, both the powers of collection, assimilation, and transformation, of the plants themselves, have been considerably augmented, and the accumulated stores of nitrogen within the soil have been rendered more available. They have, in fact, served, either directly or indirectly, as manure for both the Gramineæ and the Leguminosæ. We have, too, in the facts, an addition to the previously existing evidence in favour of the supposition that the Leguminosæ derive the large amounts of nitrogen they assimilate from the stores of the soil itself.

Turning to the amounts of mineral matter taken up under the influence of the liberal supply of it by manure, Table V., page 308, shows that, over the first period nearly one-and-two-thirds as much, over the second period more than twice as much, and over the 20 years nearly twice as much, was taken up on plot 7 as without manure. The analytical data further show that, whilst of lime and silica only about one-fourth more, of magnesia about one-half more, and of sulphuric acid and chlorine about twice as much, was taken up as without manure, of phosphoric acid there was nearly three times, and of potass nearly three-and-a-half times as much; and, with the liberal supply, and the greatly increased assimilation, of potass, there was, of soda alone less taken up and retained in the manured than in the unmanured produce; indeed, there was less than half as much, notwithstanding that soda was annually applied in the manure. Again, whilst the percentages of lime, of magnesia, and of silica, were considerably less in the dry substance of the manured than of the unmanured produce, those of the sulphuric acid and chlorine were rather higher, that of the phosphoric acid was nearly twice, and that of the potass more than twice as high; the percentage of soda, on the other hand, was little more than one-fourth as much in the dry substance of the manured as of the unmanured produce.

The general result is, that a mixed mineral manure alone has, in a very marked degree, influenced the description of plants developed, and the character of their development, greatly favouring 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 potass of the manure as mainly conducive to these effects, the phosphoric acid probably coming second in order of importance. A comparison of the results obtained by superphosphate of lime alone, and by superphosphate of lime and sulphates of soda and magnesia without potass, with those by the "mixed mineral manure" which, besides these, contained potass, will throw further light on these points.

5. *Superphosphate of Lime alone; Plot* 4–1.

Plot 4–1 has been manured with superphosphate of lime alone every year from 1859 up to the present time, or for a period of 21 years. In each of the three preceding years, however (1856–57–58), it received sawdust, at the rate of 2000 lbs. per acre per annum, the application being made to test the validity of LIEBIG'S assertion that it produced great effects by virtue of the solvent action, upon the mineral constituents of the soil, of the carbonic acid which it yields in its decomposition. Nevertheless, and notwithstanding that the sawdust annually applied contained nitrogen equal to between 4 lbs. and 5 lbs. per acre, the result was even less produce than without manure in each of the three seasons.

The following table shows the average annual yield of hay, nitrogen, and mineral matter, on plot 4–1, over the first 7, the next 10, and the total period of 17 years, from 1859–1875 inclusive, by the annual application to it of superphosphate of lime alone; and for comparison there are also given the results, over the same periods, without manure, and with the mixed mineral manure (including potass).

TABLE VII.—Average, per acre per annum, by Superphosphate of Lime alone; Plot 4–1.

	Average per acre per annum.				
	Plot 3. Without manure.	Plot 7. Mixed mineral manure.	Plot 4–1. Superphosphate lime.	Plot 4–1. + or − plot 3.	Plot 4–1. + or − plot 7.
HAY.					
	lbs.	lbs.	lbs.	lbs.	lbs.
First period, 7 years, 1859-1865	2495	3828	2732	+237	−1096
Second period, 10 years, 1866-1875 . . .	2236	4118	2384	+148	−1734
Total period, 17 years, 1859-1875 . . .	2343	3999	2527	+184	−1472
Second period, per cent. + or − first period	−10·4	+7·6	−12·7		
NITROGEN.					
First period, 7 years, 1859-1865	33·8	54·5	36·3	+2·5	−18·2
Second period, 10 years, 1866-1875 . . .	30·9	58·0	31·6	+0·7	−26·4
Total period, 17 years, 1859-1875 . . .	32·1	56·5	33·5	+1·4	−23·0
Second period, per cent. + or − first period	−8·6	+6·4	−12·9		
MINERAL MATTER (ASH).					
First period, 7 years, 1859-1865	146·5	247·8	170·8	+24·3	− 77·0
Second period, 10 years, 1866-1875 . . .	126·1	261·6	140·4	+14·3	−121·2
Total period, 17 years, 1859-1875 . . .	134·5	255·9	152·9	+18·4	−103·0
Second period, per cent. + or − first period	−13·9	+5·6	−17·8		

Thus, over both periods, the plot with the superphosphate gave more produce than that without manure; but the increase was only small, and averaged less over the second period than over the first, whilst the actual produce per acre declined more than that without manure. On the other hand, the superphosphate alone gave, over the total period of 17 years, less than two-thirds as much hay as the mixed mineral manure.

Of nitrogen, again, the increase by the superphosphate was insignificant, and both it and the actual yield declined considerably over the later period. The average annual yield of it over the 17 years was 23 lbs. less than, and did not amount to three-fifths as much as, by the mixed mineral manure.

Of mineral matter taken up, the increased amount was proportionally greater than that of either the hay or the nitrogen; but here, again, both the actual yield and the increase declined considerably over the later years. But the quantity taken up was much less, and decreased as the experiment proceeded, compared with that yielded by the mixed mineral manured plot.

The result is, that 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; whilst with the mixed mineral manure there was, instead of a reduction, an increase of all three over the second period.

The botany of the plot was comparatively little affected by the superphosphate of lime. The number and the relative predominance of species were much the same as without manure. Perhaps the most characteristic 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 of *Lotus corniculatus;* and an increase in weight of miscellaneous herbage, with a greater prevalence especially of *Ranunculus repens* and *bulbosus, Achillea millefolium* and *Rumex acetosa*.

Of the constituents supplied in the superphosphate of lime, a little more of lime and magnesia, one-and-a-half time as much sulphuric acid, and nearly twice as much phosphoric acid, were taken up under its influence as without manure. Of constituents not supplied in the manure, but derived from the soil itself, there was of potass and silica very little more taken up than without manure, but the increase of soda was somewhat greater. There was a decline in the amount taken up of every one of the mineral constituents over the second period; and this was proportionally the greatest with the soda, the silica, and the sulphuric acid, and greater in the magnesia than in either the potass or the lime.

It would appear that the superphosphate had enabled the plants to draw somewhat more largely on the resources of the soil, especially in the earlier years, but that the small increased available supply under its influence was rapidly diminishing. Lastly, the comparison of the produce by the superphosphate of lime 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, Potass; Plot* 8.

In the next table are compared the results obtained by mixed mineral manure alone in both cases, but in one including and in the other excluding potass. During the first six years of the experiments (1856–61) plots 7 and 8 each received the "mixed mineral manure," comprising superphosphate of lime, and sulphates of potass, soda, and magnesia, the only difference being that during those years, and in 1862, plot 8 also received 2000 lbs. of sawdust per acre per annum. From 1862 inclusive up to the present time, plot 7 has continued to receive the same mixed mineral manure, and plot 8 the same, excluding the sulphate of potass, but with an increased amount of sulphate of soda. The table shows the results yielded on the two plots, over the first six years, during which (with the exception of the sawdust on plot 8) both were manured alike, over the next 14 years, when the only difference was the omission of the potass and increase of the soda on plot 8, and over the total period of 20 years, 1856–1875 inclusive.

TABLE VIII.—Average, per acre per annum, by Mixed Mineral Manure, with and without Potass; Plots 7 and 8.

	Average per acre per annum.		
	Plot 7. Mineral manure, including potass, every year.	Plot 8. Mineral manure, including potass 6 years, without potass 14 years.	Plot 8. + or − plot 7.
HAY.			
	lbs.	lbs.	lbs.
First period, 6 years, 1856–1861	3835	4027	+192
Second period, 14 years, 1862–1875	4011	3098	−913
Total period, 20 years, 1856–1875	3958	3377	−581
Second period, per cent. + or − first period .	+4·6	−23·1	
NITROGEN.			
First period, 6 years, 1856–1861	56·6	60·9	+ 4·3
Second period, 14 years, 1862–1875	56·6	40·3	−16·3
Total period, 20 years, 1856–1875	56·6	46·5	−10·1
Second period, per cent. + or − first period .	0·0	−33·8	
MINERAL MATTER (ASH).			
First period, 6 years, 1856–1861	254·4	271·8	+17·4
Second period, 14 years, 1862–1875	253·7	181·9	−71·8
Total period, 20 years, 1856–1875	253·9	208·8	−45·1
Second period, per cent. + or − first period .	−0·3	−33·1	

It is to be observed that there was 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, the only difference in the treatment being that plot 8 received sawdust in addition to the other manures. It has been seen that when the sawdust was used alone it yielded no increase. Whether the result here is due to any reaction with the associated mineral manures, or to some accidental difference in the otherwise duplicate plot, it is not easy to say; but it may be remarked, in passing, that the increased amount of nitrogen taken up corresponded very closely with that contained in the sawdust.

During the next 14 years the relations are strikingly reversed in every particular. There is an average of nearly one-fourth less hay produced, and of more than one-fourth less nitrogen and mineral matter taken up, on plot 8 without, than on plot 7 with potass. In fact, the falling off in amount of produce on the exclusion of potass from the manure was very great. The number of species has remained about the same on the two plots. The percentage by weight, in the total produce, of gramineous species was, during the earlier of the 14 years, and has been on the average, greater in the produce of plot 8 without potass, but, as already referred to, it has increased on plot 7 in the later years. The percentage of the Leguminosæ has diminished exceedingly on plot 8 since the exclusion of the potass, and over the 14 years has averaged less than half as much as on plot 7. The proportion of species of other orders has, on the other hand, been higher in the produce without potass. In weight per acre, however, the yield of gramineous herbage has averaged only about four-fifths as much, that of the leguminous herbage not two-fifths as much, and that of the miscellaneous herbage also has been somewhat less, without than with the potass.

There is no very striking difference between the two plots in the relative proportion of the different species making up the gramineous herbage; but whilst with the potass there was a very marked tendency to form stem and seed, without it there was much less of this character, the herbage being more leafy, less dense, and having much less tendency to mature, some of it, indeed, appearing to dry up from exhaustion rather than to ripen.

Of leguminous herbage, there was a decline of both *Trifolium repens* and *Trifolium pratense* in the later years, both with and without the potass; but the reduction was greater without than with it. Of the deep-rooting and hardy *Lotus corniculatus* there was the more without the potass. But of the comparatively surface-rooting *Lathyrus pratensis* there was very much less without the potass. In fact, it was to the greatly increased growth of this with the potass, and to the greatly reduced growth of it without it, that the great difference in the amount of total leguminous herbage on the two plots was chiefly due.

Among the miscellaneous species those of *Ranunculus* thrived rather more without the potass, as also did *Pimpinella saxifraga*, *Centauria nigra*, and *Plantago lanceolata;* and in a greater degree *Achillea millefolium.* *Conopodium denudatum* was rather more prominent with the potass. *Rumex acetosa* was, on both plots, the most prominent of the weeds, but yielded somewhat more on plot 7 with, than on plot 8 without potass.

The analytical results, which will be fully discussed in Section III., provide the data for determining what changes in the taking up of individual mineral constituents have taken place coincidently with the great decline in the yield of hay, and the much less development of leguminous herbage, on the exclusion of potass from the manure of plot 8. Over the 14 years of this exclusion, an average of only about half as much potass was annually taken up as during the preceding six years when it was supplied, and less than half as much as on plot 7 during the 14 years of the continued application. With this reduction in the amount of potass there was considerably more, but not correspondingly more, soda taken up. Of lime, magnesia, phosphoric acid, and sulphuric acid, although all were liberally supplied, considerably less was taken up on plot 8 without than on plot 7 with the potass. Of chlorine also much less was taken up on plot 8. Of silica, which was not supplied, even rather more was taken up without than with the potass, but with this exception, and that of soda already referred to, less of every mineral constituent was taken up on plot 8 without than on plot 7 with the potass. Of percentage in the dry substance of the produce, however, that of lime, magnesia, phosphoric acid, sulphuric acid, and chlorine, was nearly the same without and with the potass; that of soda and of silica was much higher, but that of potass was not two-thirds as high, without the potass, though it was still much higher than without manure, as also was the percentage of phosphoric acid; but that of the other constituents was, for the most part, much the same as without manure, excepting the lime, which was considerably less both without and with the potass.

A consideration of the facts enumerated can leave no doubt that it was to a relative deficiency of available potass that the falling off, not only in the total weight of produce, but also in the description, and in the character of development, of the herbage, is to be attributed.

Notwithstanding the great reduction in the amount of produce, and in the amount of potass taken off in the crop, after the cessation of its application, there was still, in every one of the 14 years, much more potass taken up than without manure. There was, however, something like a gradual reduction of the excess from year to year, and it averaged not much more than half as much over the second as over the first seven of the 14 years. It is obvious, therefore, that the unexhausted residue of the potass applied during the first six years has, in a considerable proportion at any rate, remained in the soil within the range of the roots, but that only a limited and gradually decreasing proportion has been available each year. The questions arise—how much unexhausted residue did remain at the end of the six years of the application? and whether the whole of it has as yet been yielded up? In estimating the amount of unexhausted residue, we have first to consider whether the whole of the potass of the crop was derived from that which was artificially supplied, or whether only so much of it as was in excess of that taken up without manure?

If we assume, for the sake of illustration, that the potass artificially supplied was the most readily available, and that the crop relied entirely upon it so long as it lasted, the result would be that only about 376 of the 900 lbs. applied, remained as residue after the first six years, and that nearly the whole of this was taken out during the next seven years. That it was not all recovered by that time would appear from the fact that in every one of the following seven years there was still considerably more potass in the crop of plot 8 than in that without manure.

If, on the other hand, we suppose that the soil yielded up as much potass from its own stores to the crop of plot 8 as to that without manure, there would remain at the end of the six years of the application 567 lbs., or nearly two-thirds of the whole supplied still to be accounted for. On the same supposition, at the end of the next 14 years there would still remain more than 300 lbs. of the supplied potass as yet unaccounted for. That some did, and does still, remain in an available condition may be concluded from the fact that there was a considerable excess of produce, of mineral matter, and of potass, removed from plot 8 compared with plot 3 in the two succeeding years, 1876 and 1877, and there was again an excess of produce in 1878.

Whether, however, the soil did actually yield up from its own resources more or less to this manured than to the unmanured produce, we have not the means of determining. It has been seen that the superphosphate of lime applied alone on plot 4–1 enabled the herbage to take up very little more potass from the soil. But in that case there was extremely little increased growth. On plot 8, on the other hand, there was, besides superphosphate, the residue of potass previously applied, an annual supply of sulphates of soda and magnesia also, and with these considerably increased luxuriance of growth. Under such conditions the roots of the herbage would doubtless have possession of an increased range of soil and subsoil, and as it is obvious that notwithstanding the considerable residue of previously supplied potass the growing plants nevertheless suffered from a deficient available supply of it relatively to other constituents, it would appear probable that they would extract from the soil, at any rate as much as the unmanured herbage. Our knowledge, or rather our ignorance, of the condition in which the available portion of the potass of the soil itself exists within it, and is taken up by the roots, or of the condition in which the unexhausted residue of the previously supplied potass is retained, and becomes available in so piece-meal a manner, is such that it is impossible to come to any definite conclusion on the point. It will be seen that the facts suggest an interesting and useful line of experimental enquiry.

That certain soils do, as a matter of fact, retain a residue of supplied potass, and in a slowly available condition, for very many years, is conclusively proved by evidence of very different kinds. Thus, in the experiments at Rothamsted in which wheat has now been grown for 36 years in succession on the same land, the effects of the residue of potass supplied more than 28 years ago are still traceable in an increased produce compared with that where there had not been such supply, and also in an increased amount of potass in the crops grown. Further, on the examination of the soils of some of the plots of that same field, Baron LIEBIG'S son, HERMANN VON LIEBIG, found the amounts of both potass and phosphoric acid considerably greater, especially in the upper layers, the greater had been the previous supplies by manure. Lastly, Dr. VOELCKER'S analyses of the drainage waters from the different plots of the same field showed very much less loss of potass 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 potass or phosphoric acid.

To sum up in regard to the effects of the different mineral manures when used without artificial nitrogenous supply: the comparison of the results obtained without manure, with superphosphate of lime alone, and with a mixed mineral manure with, and without, potass, brings clearly to view the much more striking influence of an increased supply of potass, than of lime, magnesia, soda, phosphoric acid, or sulphuric acid; and it will be observed that this is quite consistent with the facts adduced in Table I., and context, 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 potass at command, more of the other constituents enumerated above were taken up, and even when superphosphate of lime was used alone, considerably more phosphoric acid was taken up, but coincidently with this there was but little increase of produce, and very little increase in the amount of nitrogen assimilated.

The more special effects of the mineral manures, and particularly of the artificial supply of potass, on the botanical and chemical characters of the herbage, will be discussed in Parts II. and III.

Having now considered the results obtained by nitrogenous manures alone, and by mineral manures alone, we have next to call attention to those yielded by mixtures of the two. Following somewhat the same order of illustration as in regard to nitrogenous manures used alone, we will discuss—first the effects of a given amount of nitrogen applied as ammonia-salts, then of double the quantity, then of the same (the single) 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 potass, 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 potass, and with the mixed mineral manure excluding potass.

7. 400 *lbs. Ammonia-Salts with Mixed Mineral Manure containing Potass; Plot* 9.

The next table shows the results obtained by this mixture, side by side with those, over the same periods, by the same quantity of ammonia-salts used alone, and by the same mixed mineral manure used alone.

TABLE IX.—Average, per acre per annum, by 400 lbs. Ammonia-Salts, with Mixed Mineral Manure containing Potass; 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.
HAY.					
	lbs.	lbs.	lbs.	lbs.	lbs.
First period, 10 years, 1856–1865	3420	3797	6002	+2582	+2205
Second period, 10 years, 1866–1875	2471	4118	5421	+2950	+1303
Total period, 20 years, 1856–1875	2946	3958	5711	+2765	+1753
Second period, per cent. + or − first period	−27·7	+8·5	−9·7		
NITROGEN.					
First period, 10 years, 1856–1865	57·9	55·2	75·7	+17·8	+20·5
Second period, 10 years, 1866–1875	47·3	58·0	70·7	+23·4	+12·7
Total period, 20 years, 1856–1875	52·6	56·6	73·2	+20·6	+16·6
Second period, per cent. + or − first period	−18·3	+5·1	−6·6		
MINERAL MATTER (ASH).					
First period, 10 years, 1856–1865	181·2	246·2	368·3	+187·1	+122·1
Second period, 10 years, 1866–1875	108·9	261·6	301·0	+192·1	+ 39·4
Total period, 20 years, 1856–1875	145·1	254·0	334·6	+189·5	+ 80·6
Second period, per cent. + or − first period	−39·9	+6·3	−18·3		

By this combination of ammonia-salts and mixed mineral manure supplying all the mineral constituents of the crop, except silica, we have, over 20 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 one-and-a-half time as much as by the same mineral manure used alone. There was, however, a falling off in the produce of the last 10 years compared with the first 10, of nearly 10 per cent., or in nearly as great a proportion as without manure, but in very much less proportion than with the ammonia-salts without the mineral manure; whilst, on the other hand, there was an increase instead of a reduction in the later years with the mineral manure alone.

The average annual yield of nitrogen per acre was more than twice as much as without manure, more than one-and-one-third time as much as by the same amount of ammonia-salts alone, and nearly one-and-one-third time as much as by the same mineral manures used alone. There was a falling off in the yield over the second 10 years compared with the first 10, but in less proportion than in that of the hay, in less proportion than without manure, and in much less than where the ammonia-salts were used alone; whilst, as with the produce, so with the nitrogen, there was an *increased* yield over the second 10 years with the mineral manures used alone.

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 one-and-one-third time as much as when the same mineral manure was used without ammonia-salts. With the mineral manures alone, however, there was a slight increase in the amount taken up over the second 10 years; but when used with the ammonia-salts there was a reduction of 18 per cent., or in greater proportion than without manure, but in only about half the proportion as when the ammonia-salts were used alone.

Thus, with the ammonia-salts and the mixed mineral manure together, there was a great increase in the produce of hay, and in the amounts of nitrogen and of mineral matter taken up, compared either with the result without manure, with the ammonia-salts alone, or with the mineral manure alone. But whilst with the mineral manure alone there was an increase in all three items of yield over the second compared with the first 10 years, there was with the ammonia-salts and mineral manure together a reduction in all three, but in much less proportion than when the ammonia-salts were used alone.

In explanation of these great differences in the amounts of produce yielded, and of nitrogen and mineral matter taken up, it is essential to take into consideration the very different character of the herbage in the several cases.

Without manure the herbage was very complex, and though diminutive, a relatively large proportion of the plants developed stem, showed tendency to seed formation, and would be comparatively mature at the time of cutting. The complex herbage contained a comparatively large proportion of other than gramineous species, of which the Leguminosæ would be nearly twice as rich in nitrogen as the grasses, and the miscellaneous species would also be somewhat richer. The result is that without manure there was, as already pointed out, an average over the 20 years of nearly twice as much nitrogen as would be obtained in a gramineous crop growing separately, such as wheat or barley.

With the mixed mineral manure, including potass, used alone, there was, it will be remembered, besides a considerable increase of produce due to gramineous species, a proportionally much greater increase of leguminous herbage, and also some increase due to miscellaneous species. Under these conditions, there was a considerably increased amount of nitrogen taken up without any being supplied in the manure, and it was concluded that it was derived from the stores of the soil itself.

With ammonia-salts alone, on the other hand, there was scarcely a trace of leguminous herbage, and very little due to any miscellaneous species, except *Rumex acetosa*. The produce was very characteristically gramineous. In the later years nearly one-half consisted of one species, *Festuca ovina*, and about a quarter of *Agrostis vulgaris*. This almost exclusively, and very simple, gramineous herbage showed, moreover, very little tendency to form stem and seed, or to mature, but consisted chiefly of stunted, and very dark green, leafy growth. This colour indicates a high percentage of nitrogen in the dry substance, or more properly speaking a deficient assimilation of carbon in proportion to the nitrogen taken up, owing to deficient mineral supply. The result was a considerable increase in the amount of nitrogen taken up compared with that without manure, but still, less than with the mineral manure alone without nitrogen.

With the mixture of the nitrogenous and mineral manures, on the other hand, the produce was still more gramineous than with 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 here, the still more characteristically gramineous herbage was made up in much less degree of a few species only. 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, Holcus lanatus,* and *Dactylis glomerata* were only very moderately, and every other grass very sparingly, represented, 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* was the most prominent of all. The character of development of the grasses was, moreover, totally different; there being, when mineral manures, including potass, as well as ammonia-salts, were used, 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.

Owing, however, to the totally different proportion of gramineous, leguminous, and other species in the herbage without manure, or with mineral manures alone, on the one hand, and with ammonia-salts alone, or ammonia-salts with mineral manure on the other, it is very difficult to decide on what basis to estimate how much of the nitrogen taken up where it was artificially supplied was due to natural sources, and how much therefore is to be attributed to the supplies by manure when the ammonia-salts were used alone, and how much more when these were used in conjunction with the mineral manure? It is probable that, even when used in conjunction with the mineral manure, not much more than half the supplied nitrogen was taken up, so that the reduction in produce over the second 10 years would not seem to be connected with a deficiency of available nitrogen.

The reduction in the amount of total mineral matter taken up was greater than in that of the nitrogen. The falling off in produce would, so far, seem more probably connected with a deficiency of available supply of one or more of the mineral constituents. Calculation shows, however, that more, and generally much more, of each constituent, with the one exception of silica, was applied each year than was removed, 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. Again, as will be seen further on, when the same mineral manures were used with an increased amount of ammonia-salts, a larger amount of every one of the mineral constituents, excepting lime, was taken up; and of this, very much more was annually supplied than was taken up. Nor can the falling off be attributed wholly to less favourable seasons during the second 10 years; for, as the next illustrations will show, some other combinations of manure yielded more hay, containing more nitrogen, and more mineral matter, over the second period than over the first. It should perhaps be noted that one end of the plot was apparently to the eye to some extent injured by the roots of a large tree, and this injury was the greater in the later years.

The actual falling off in the amount of mineral constituents taken up over the second period was considerable, and it was pretty equal in the soda, the chlorine, the lime, and the sulphuric acid; it was about twice as great in the silica, but very slight indeed in either the potass or the phosphoric acid. The decreasing amount of soda, chlorine, and sulphuric acid, taken up and retained, with at the same time an all but maintained assimilation of potass and phosphoric acid, would indicate increased tendency to stem and seed formation, and to maturation; whilst, the deficiency of lime, and of silica, is also consistent with a less amount of leaf and greater amount of stem. In fact, the percentage in the dry matter—of lime, magnesia, soda, sulphuric acid, and silica, was lower than in the produce either without manure or with the ammonia-salts alone; whilst that of the potass was nearly twice as high as without manure, and more than twice as high as with the ammonia-salts alone, and that of the phosphoric acid was also very much higher than either without manure, or with ammonia-salts alone.

The probability is, that the reduced assimilation of both nitrogen and most of the mineral constituents over the second period was 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 aboveground development, with which would vary, not only the range and power of collection from the resources of the soil, but also the requirement for this or that individual constituent. And it is probable that, in addition to these conditions affecting the whole plot, some of the reduced assimilation is to be explained by the action of the tree-roots above referred to.

8. 400 *lbs. Ammonia-Salts, with Mixed Mineral Manure containing Potass, and* 2000 *lbs. cut Wheat Straw; Plot* 13.

Table X. shows the results obtained over the same 10, 10, and 20 years, on plot 13, with the same quantity of ammonia-salts, and the same description and amount of mineral manure, applied every year, as on the last plot considered (9), but with 2000 lbs. of cut wheat straw per acre per annum in addition. The chief object of the application of the straw-chaff was to supply silica, and carbonaceous organic matter, somewhat in the same condition as they are provided in dung. It obviously also provides some other mineral constituents, and a little nitrogen, but all presumably in an only slowly available condition.

TABLE X.—Average, per acre per annum, by 400 lbs. Ammonia-Salts, with Mixed Mineral Manure containing Potass, and 2000 lbs. cut Wheat Straw; Plot 13.

	Average per acre per annum.		
	Plot 9. Mineral manure and 400 lbs. ammonia-salts.	Plot 13. As plot 9, and 2000 lbs. cut wheat-straw.	Plot 13 + or − plot 9.
HAY.			
	lbs.	lbs.	lbs.
First period, 10 years, 1856–1865	6002	6186	+ 184
Second period, 10 years, 1866–1875	5421	6679	+1258
Total period, 20 years, 1856–1875	5711	6432	+ 721
Second period, per cent. + or − first period	− 9·7	+8·0	
NITROGEN.			
First period, 10 years, 1856–1865	75·7	79·5	+ 3·8
Second period, 10 years, 1866–1875	70·7	87·3	+ 16·6
Total period, 20 years, 1856–1875	73·2	83·4	+ 10·2
Second period, per cent. + or − first period	− 6·6	+9·8	
MINERAL MATTER (ASH).			
First period, 10 years, 1856–1865	368·3	389·2	+ 20·9
Second period, 10 years, 1866–1875	301·0	382·8	+ 81·8
Total period, 20 years, 1856–1875	334·6	386·0	+ 51·4
Second period, per cent. + or − first period	−18·3	−1·6	

There is here considerably more average produce of hay, and more of nitrogen and mineral matter removed, over the 20 years, than by the same manures without the straw. There is also, instead of a reduction, a considerable increase, in the yield of hay and of nitrogen, and a nearly equal yield of mineral matter, over the second 10 years compared with the first.

The exact explanation of the much greater productiveness where the cut straw was used is not very obvious, but it may be well be enumerate some of the coincidents of this result.

Plot 13, like plot 12, the duplicate unmanured plot, is earlier shaded from the afternoon sun than the remaining plots, and plot 12 gave, every year of the 20, excepting the first two and the twelfth, more produce than the other unmanured plot (3). Plot 13 again, though it gave less produce than plot 9 during the first three years, has, with one slight exception, given more every year since, and in the latter half of the period very much more. But, besides any advantage from position and shade of plot 12 over plot 3, the examination of, and the determinations of nitrogen in, the subsoil of plot 12 showed it to be much more mouldy and much richer than that of plot 3, and it was concluded that the plot consisted, in great part at any rate, of made or moved ground, the site possibly of a filled-up hollow, or of a removed and levelled plantation or hedge green. Neither the sections nor the analyses of the subsoil of plot 13 showed any such characters, however, so that, independently of manure, the only known difference between it and plot 9 was in its earlier afternoon shade.

The herbage of plot 13 has become even more prominently gramineous than that of plot 9. Leguminosæ have almost equally disappeared on both; and the Miscellaneæ have also greatly reduced on both, *Rumex acetosa* being the only very prominent weed on either, *Conopodium denudatum* coming next. The increase of produce on plot 13 was, in fact, almost exclusively due to an increase in gramineous herbage, and this, compared with that of plot 9, contained very much more *Dactylis g.*, which here becomes the most prominent species; about the same proportion of *Agrostis v.*, considerably less *Holcus l.*, very much less of *Festuca o.*, and especially of *Poa prat.*; but, on the other hand, a fair proportion of *Alopecurus p.*, which is scarcely represented on plot 9; whilst, *Avena pub.* and *flav.*, and *Poa triv.* have gone down very much on both plots. Thus, compared with that of plot 9, the produce of plot 13 (with the straw) was somewhat differently made up, but it comprised a considerable proportion of several of the freer-growing grasses. These, too, manifested considerable tendency to form strong seed-stems.

These characters indicate liberal nitrogenous and mineral supply within the soil, and as they predominated more on plot 13 than on plot 9, it would be supposed that these conditions prevailed on it the more.

Supposing the whole of the nitrogen of the staw became available, it would supply about 9 lbs. per acre per annum, and presumably a smaller proportion of it at first, and more and more each year. Consistently with this, there was either no excess of yield of hay and of nitrogen, or but little, on plot 13 compared with plot 9, in the earlier years, but a considerable excess over the latter half of the period; and there was an increase of about 10 lbs. of nitrogen per acre per annum over the 20 years. It is probable, however, that, owing to various conditions favourable to luxuriance, the growing plants were enabled to avail themselves of more also of the other supplies of nitrogen within the soil.

Of mineral matter, the crop of plot 13 took up, over the first 10 years rather more than 20 lbs., over the second 10 rather more than 80 lbs., and over the 20 years rather more than 50 lbs., per acre per annum, more than that of plot 9. There was some increase in the amounts taken up of all the mineral constituents, but the most marked was—of potass an average of about 23 lbs., of phosphoric acid about 4 lbs., and of chlorine about 8 lbs., with in each case more over the second period than the first, There was, too, an average of about 8 lbs. more silica annually taken up on the straw plot, but less over the second period than the first. Of lime, magnesia, and phosphoric acid, the straw applied would contain considerably more, and of silica about eight times more, than the increased amount of them taken up where it was used. But of potass the amount contained in the straw would be much less than the increased amount of it taken up. There is evidence here, again, that owing to the increased activity of growth from whatever cause, the growing herbage had availed itself of more of the other supplies within the soil than those actually contributed by the straw itself.

Something may be due to the "mulching" effect, or protection given by the straw to the young shoots, and something (though the effects obtained by sawdust would not lead us to expect much) to a slightly increased supply of carbonic acid to the young plants, and to the soil. At any rate the herbage shows a somewhat better colour in the early spring.

Upon the whole, there can be little doubt that some of the increased luxuriance under the influence of the straw-manuring is to be attributed to an increased supply of manurial constituents, and some may be due to its mechanical effects. But the question suggests itself—whether something may not be also due to the position of the plot as above referred to, and something possibly also to an unknown difference in the character of the soil and subsoil? Finally, it must not be overlooked that if the combination of the conditions of manure, soil, and local circumstances, was more favourable to certain freer-growing species, these, as a coincident of the character of freer growth, would necessarily be able to avail themselves more than others could do, of the same supplies within the soil. In fact, something is to be attributed to the greater powers of food-collection of the species favoured, as well as to the somewhat increased supplies by manure. With an increased faculty to take up food, more of it is taken up than would result from the mere increase of supply; that is, more than would be the case were one and the same species, with one and the same habit and functional capacity, growing on the two differently manured plots.

9. 800 *lbs. Ammonia-Salts, and Mixed Mineral Manure containing Potass; Plots* 11–1 *and* 11–2.

The next illustrations show the effects of a considerably increased supply of ammonia-salts, used in conjunction with the same mixed mineral manure, including potass, as on plot 9. During the first three years double the amount, or 800 lbs. per acre, of ammonia-salts, containing about 200 lbs. of ammonia, equivalent to about 164 lbs. 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 so has remained up to the present time. At the period of this change, too, that is, 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 (1862–1870), 200 lbs. of a crude silicate of lime, and 200 lbs. of a crude silicate of soda, and afterwards 400 lbs. of the silicate of soda, per acre per annum, were employed.

The following table shows the produce of hay, of nitrogen, and of mineral matter, over the first 10, the second 10, and the total period of 20 years, on each of the two portions of the plot—11–1 continuously without, and 11–2 for the last 14 years with, the silicate. For comparison there is also again given, the results obtained on plot 9, with the same mixed mineral manure and only 400 lbs. of ammonia-salts, per acre per annum, over the whole period.

TABLE XI.—Average, per acre per annum, by 800 lbs. (or 400 lbs.) of Ammonia-Salts, and Mixed Mineral Manure, without, and with, the addition of Silicates; Plots 11–1 and 11–2.

	Average per acre per annum.				
	Plot 9. Mineral manure, and 400 lbs. ammonia-salts.	Plot 11–1. Mineral manure, and 800 lbs.* ammonia-salts.	Plot 11–2. As plot 11–1, and silicates.	Plot 11–1. + or − plot 9.	Plot 11–2. + or − plot 11–1.
HAY.					
	lbs.	lbs.	lbs.	lbs.	lbs.
First period, 10 years, 1856–1865	6002	6913	7077	+911	+164
Second period, 10 years, 1866–1875	5421	6006	6909	+585	+903
Total period, 20 years, 1856–1875	5711	6459	6993	+748	+534
Second period, per cent. + or − first period	−9·7	−13·1	−2·4		
NITROGEN.					
First period, 10 years, 1856–1865	75·7	102·7	103·7	+27·0	+1·0
Second period, 10 years, 1866–1875	70·7	103·5	111·7	+32·8	+8·2
Total period, 20 years, 1856–1875	73·2	103·1	107·7	+29·9	+4·6
Second period, per cent. + or − first period	−6·6	+0·8	+7·7		
MINERAL MATTER (ASH).					
First period, 10 years, 1856–1865	368·3	420·7	435·9	+52·4	+15·2
Second period, 10 years, 1866–1875	301·0	339·7	392·1	+38·7	+52·4
Total period, 20 years, 1856–1875	334·6	380·2	414·0	+45·6	+33·8
Second period, per cent. + or − first period	−18·3	−19·3	−10·1		

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

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

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 14 years of the 20 has further increased the amounts of hay yielded, and of nitrogen and mineral matter taken up.

Bearing in mind that in the fourth, fifth, and sixth, of the first 10 years, only the same amount of ammonia-salts was applied on the plots 11 as on plot 9, and that the double amount was applied in each of the last 10 years, it will be observed that there was nevertheless a considerable falling off in the produce of hay, and in the quantity of mineral matter taken up, during the second 10 years, where the silicates were not also applied. Where the silicates were applied, however, the falling off in the produce was very trifling, and that of the mineral matter taken up much less than where they were not applied; whilst, under their influence, there was also a considerably greater increase in the amount of nitrogen taken up over the second 10 years.

With regard to the nitrogen, it is remarkable that, with the enormous amount of about 200 lbs. of ammonia, corresponding to about 164 lbs. of nitrogen, applied per acre per annum, for so many years, there was, so far as can be judged, as large if not a larger proportion of that 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, very abnormally high; and, as already pointed out, such a condition indicates a deficient assimilation of other constituents in proportion to the nitrogen taken up. This result may be due to a deficiency of available mineral constituents, or to the limitation of the climatic characters of the seasons for the assimilation of a larger amount of carbon by the quantity and quality of the leaf-surface presented over a given area; or the effect may be due to a combination of these causes.

The further increased total yield of hay, of nitrogen, and of mineral matter, where the silicates of soda and lime were used, and at the same time a decrease over the second period compared with the first in the amount of mineral matter, but an increase in that of the nitrogen, taken up, would seem to indicate a relative deficiency of available supply within the soil of mineral constituents compared with that of nitrogen. Still, a limitation of the climatic characters of the seasons may have had some share in the limitation of the amount of carbon assimilated, or, in other words, of the amount of produce grown.

With a view, if possible, of further elucidating the conditions and the results of the growth induced, let us briefly consider—what was the difference in the botanical character of the herbage developed by the single and by the double application of ammonia-salts, and without and with silicates, respectively? and what were the chief differences in the chemical composition of the hay?

In the unmanured hay there are nearly 50, and in that grown by mineral manures alone (including potass) more than 40, species represented. In that grown by the mineral manure and the smaller amount of ammonia-salts (plot 9) there are, however, scarcely 30; and in that by the double amount of ammonia-salts and the mixed mineral manure, both without and with silicates, there have been, in recent years, less than 20, and even as few as 16. The reduction in the number of species where mineral manures and ammonia-salts are used together is in the gramineous, the leguminous, and the miscellaneous, but chiefly in the miscellaneous species; and, comparing the produce of plot 9 with the single, and of the plots 11 with the double amount of ammonia-salts, the reduction, both in number, percentage, and actual weight, is again very prominently in the miscellaneous species. In fact, the produce on the plots 11 has become almost exclusively gramineous, and considerably more so than on plot 9 with the smaller quantity of ammonia-salts.

The most prominent grass on the plots 11 with the excessive amount of ammonia-salts (as was the case on plot 13 with half the quantity and the straw chaff) has been, both actually and compared with plot 9, the very free-growing *Dactylis glomerata*; but, of late years, it has appeared to be declining, especially on plot 11–2, with the silicates, where it seems to be giving place largely to *Alopecurus pratensis*, with which occur in considerable quantity, and each increasing on both plots, *Agrostis vulgaris*, *Holcus lanatus*, and *Avena elatior*. The five grasses enumerated make up a very large proportion of the total produce, whilst *Poa pratensis* has gone down much, and *Poa trivialis* has almost disappeared. On plot 11–1, without the silicates, the *Dactylis* has also lost the first place; but instead of *Alopecurus*, which is somewhat going down, *Agrostis* is coming forward the most prominently; *Holcus* and *Avena elatior* coming next, and increasing. On the other hand, *Festuca ovina*, though still occurring in only small proportion, seems to be rather gaining ground on both plots. The grasses which are the most strikingly decreasing, both without and with the silicates, are the two Poas, especially the *trivialis*, and, without the silicates, perhaps the *Alopecurus*.

On all three plots, 9, 11–1, and 11–2, there has been either no leguminous herbage found, or only a small fraction of 1 per cent. of it.

The most prominent species belonging to the "miscellaneous" orders is the *Rumex acetosa*, which, however, seems to be going down on all, but the most on the plots 11. Next in order of prevalence are *Conopodium denudatum* and *Achillea millefolium*, both of which are decreasing, and on the plots 11 have nearly disappeared.

Thus, 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. 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.

Coincidently with these botanical and other characteristics of the herbage grown by mineral manures and ammonia-salts, we have, as already stated, an abnormally high percentage of nitrogen in the produce when an excessive amount of it is supplied in the manure. There is also a somewhat high percentage of mineral matter in the dry substance of these large, coarse, unevenly ripened, and almost exclusively gramineous crops.

Further, the results of the ash-analyses, which will be fully considered subsequently, show some striking differences in the mineral composition of the produce. Thus, there is a strikingly lower percentage of lime, a lower percentage of magnesia, and, notwithstanding 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 potass and phosphoric acid, but especially of potass, 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. Again, whilst the percentage in the dry substance, of lime, magnesia, soda, sulphuric acid, and silica, has decreased over the later compared with the earlier years, that of the potass and phosphoric acid (and also that of 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.

Comparing plots 11–1 and 11–2, both with the mixed mineral manure and the large amount of ammonia-salts, but 11–1 without, and 11–2 with silicates, the only noticeable difference in the percentage mineral composition of the herbage is, that there is a slightly higher percentage of silica in that where it was applied, and with this there is a less percentage of potass, and a less increased percentage of it over the later years. There is, at the same time, a somewhat less excessive percentage of nitrogen where the silicates were used. The increased actual amount per acre of mineral matter removed where the silicates were applied was, however, much greater than is represented by the increased amount of silica taken up (which was only about 7 lbs. per acre per annum out of the 400 lbs. of crude silicates used). Nor is this result to be explained by supposing that there was a deficiency of available soda and lime where the silicates were not applied, since but a small proportion of that otherwise supplied of either had been utilised; and there was, therefore, unless lost by drainage, an annually increasing residue of them accumulating within the soil. There can, indeed, be little doubt that, 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 effective in other ways than merely as supplies of either silica, 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, potass, phosphoric acid, sulphuric acid, and chlorine, as well as more silica, lime, and soda, taken up; and, with these, more carbon assimilated.

In reference to the differences in the mineral composition of the hay grown under different manurial conditions, and accordingly possessing very different botanical and other characteristics, it is to be borne in mind that the dry matter of the species of the "Miscellaneous" orders 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, further, that the less matured the produce, the higher, as a rule, will be the percentage of mineral matter in its dry substance. Again, the ash of the leguminous herbage contains the highest, that of the miscellaneous a lower, and that of the gramineous the lowest percentage of lime. On the other hand, the ash of the gramineous herbage is richer in potass than that of either the miscellaneous or the leguminous, and it will be the richer in potass, and the less rich in lime, the greater the proportion of stem to leaf. Hence, we should expect, as we find, less lime and more potass in the coarse, almost exclusively gramineous, and stemmy herbage.

In conclusion, although with the mixed mineral manure and the double amount of ammonia-salts the large average amount of about 3 tons of hay has been annually obtained over a period of 20 years and more, and an even somewhat larger proportion of the supplied nitrogen was taken up than when only half the quantity was applied, there was not a corresponding increase in the amount of vegetable matter grown. There was, nevertheless, annually much more nitrogen, and much more of every one of the mineral constituents, supplied in the manure than was contained in the increase of crop. That the produce was not greater would appear, therefore, to be due to other conditions than a deficiency of any of the constituents derived from the soil, unless, indeed, of silica in an available form. It was more probably due to defective atmospheric, that is climatic, conditions, limiting the assimilation of carbon; in other words, to a limitation in the amount, and adaptation, of the light, heat, and moisture, necessary for the assimilation over a given area of a larger amount of that substance. And, as there has been, not only a less amount of growth in proportion to the nitrogen taken up, but, notwithstanding an annually increasing manurial residue within the soil, a more or less declining amount over the later years, it would appear not improbable that, with the characters of the herbage described, there has been a less capability of the plants, either to gather up the accumulating stores within the soil, or to take full advantage of such atmospheric conditions as did exist.

10. 550 *lbs. Nitrate of Soda, with Mixed Mineral Manure containing Potass; Plot* 14.

We have already compared the effects of a given amount of nitrogen applied as ammonia-salts with those of the same amount applied as nitrate of soda, when each was used alone. We have now to compare their effects when each is employed in conjunction with the usual "mixed mineral manures." The comparison will be between the results on plot 9, with the mineral manures and the nitrogen applied as ammonia-salts, and those on plot 14, with the same mineral manures and the same quantity of nitrogen applied as nitrate of soda. As, however, the experiments with the nitrate were not commenced until two years later than those with the ammonia-salts, the periods selected for illustration will be 8, 10, and 18, instead of 10, 10, and 20 years.

TABLE XII.—Average, per acre per annum, by 550 lbs. Nitrate of Soda, and Mixed Mineral Manure, including Potass; Plot 14.

	Average per acre per annum.		
	Plot 9. Mineral manure and ammonia-salts.	Plot 14. Mineral manure and nitrate soda.	Plot 14 + or − plot 9.
HAY.			
	lbs.	lbs.	lbs.
First period, 8 years, 1858–1865	5904	5944	+ 40
Second period, 10 years, 1866–1875	5421	6777	+1356
Total period, 18 years, 1858–1875	5636	6407	+ 771
Second period, per cent. + or − first period . . .	− 8·2	+14·0	
NITROGEN.			
First period, 8 years, 1858–1865	75·4	67·6	− 7·8
Second period, 10 years, 1866–1875	70·7	70·6	− 0·1
Total period, 18 years, 1858–1875	72·8	69·3	− 3·5
Second period, per cent. + or − first period . . .	− 6·2	+ 4·4	
MINERAL MATTER (ASH).			
First period, 8 years, 1858–1865	356·1	357·2	+ 1·1
Second period, 10 years, 1866–1875	301·0	373·2	+ 72·2
Total period, 18 years, 1858–1875	325·5	366·1	+ 40·6
Second period, per cent. + or − first period . . .	−15·5	+ 4·4	

When 550 lbs. of nitrate of soda were used alone there was considerably more yield of hay, of nitrogen, and of mineral matter, than when 400 lbs. of ammonia-salts were employed, and there was also a much less reduction of yield over the later compared with the earlier years. Here, again, when each of the nitrogenous manures is used in conjunction with the mixed mineral manure, we have a much greater produce of hay when the nitrogen is applied as nitrate of soda than when as ammonia-salts. 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.

When considering the effects of the two nitrogenous manures used alone, attention was called to the fact that the nitrogen of the nitrate of soda distributed much more rapidly through the soil than that of the ammonia-salts (p. 306), and that, coincidently, not only were those plants favoured by the nitrate which could the most rapidly take up the supplies near the surface, but those also which had a tendency to distribute their roots in the deeper layers; and hence, under their influence, there was a greater development of root in the lower layers, and with this the growing herbage acquired possession of wider and deeper ranges of soil and subsoil.

This was strikingly illustrated in the results obtained on the two plots now under consideration (14 and 9) in the season of drought of 1870. In that year the produce of hay on plot 9, with the mixed mineral manure and ammonia-salts, was nearly 23 cwts. below its average amount, whereas on plot 14 it was less than $1\frac{1}{2}$ cwt. below its average. In view of this extraordinary difference of result from the same mineral manure and the same amount of nitrogen applied, not only the description of plants grown, but the distribution of the roots was examined; and samples of the soils were taken, every nine inches, down to a depth of 54 inches, on these and on the unmanured plot, for the purpose, among others, of determining the amount of moisture remaining in the soil at the different depths.

The following table shows the percentage of moisture (as determined by drying at 100° C., and including the loss by evaporation during preparation for analysis) in the samples of the different soils at the different depths.*

TABLE XIII.—Samples of soil collected July 25–6, 1870.

Depth of sample.	Per cent. moisture.		
	Plot 3. Without manure.	Plot 9. Mineral manure and ammonia-salts.	Plot 14. Mineral manure and nitrate soda.
First nine inches . . .	10·83	13·00	12·16
Second nine inches . .	13·34	10·18	11·80
Third nine inches . . .	19·23	16·46	15·65
Fourth nine inches . .	22·71	18·96	16·30
Fifth nine inches . . .	24·28	20·54	17·18
Sixth nine inches . . .	25·07	21·34	18·06
Means	19·24	16·75	15·19

Now, if we assume, as is sufficiently near the truth for the purpose of illustration, that down to the total depth of 54 inches an acre of the soil would weigh (exclusive

* *See* "Effects of the Drought of 1870 on some of the Experimental Crops at Rothamsted." (Jour. Roy. Ag. Soc. Eng., vol. vii., S.S. Part I.)

of stones) 18,000,000 lbs., it would result that, down to that depth, the soil of plot 9 (with the ammonia-salts) contained 200 tons, and that of plot 14 (with the nitrate) 325 tons, less water per acre, than that of the unmanured plot to the same depth—quantities which correspond respectively, to about two, and three-and-a-quarter, inches of rain. And, from the great difference in the percentage of moisture at the lower depths, it may be concluded that the difference extended deeper still.

It would thus seem that the subsoil had contributed more water to the growing vegetation on the manured than on the unmanured land, and much more where the nitrate was applied than where the ammonia-salts were used. But the questions arise—if the unmanured subsoil retained so much more water, why did the crop suffer from the drought? and why did the crop manured with the ammonia-salts suffer so much more than that with the nitrate? The answer, briefly stated, is that different plants, of different habits of growth, prevailed on the respective plots, according to the conditions of manuring.

On the unmanured plot there was the greatest number of species, but those which prevailed had finer and less vigorous roots, which penetrated comparatively little below the surface soil; the raw clay of the subsoil was consequently much less changed, and it had yielded up very much less moisture to the growing crop.

On the plot manured with the mineral manure and ammonia-salts free-growing grasses predominated, but chiefly those whose underground habit rendered them dependent for their food and moisture in a great measure on the stores to be found in the surface soil, and in the upper layers of the subsoil. Still, owing to the increased vigour of growth under the influence of the manure, more moisture was obtained from the lower layers; probably, in part directly by the roots, and in part by the aid of capillary action induced by the pumping out of the upper layers; and the results indicated that the action extended beyond the depth to which the samples were taken.

On the plot manured with mineral manure and nitrate of soda, in that year one species, the *Bromus mollis*, contributed nearly half the produce; its wiry roots have a very characteristically downward tendency, and they were found to penetrate deeper than those of any other of the grasses, and, therefore, to have acquired command of lower layers than any associated with them; and this was especially so compared with the herbage on plot 9, with the ammonia-salts. The result was that the lower layers were pumped drier, and, under these circumstances, the drought affected the amount of crop but little.

In accordance with these facts as to the difference in the character of growth, and the amount of water found at different depths, great differences were observed in the characters of the soil and subsoil of the several plots.

The first nine inches of soil of the unmanured plot possessed the character of mould in nearly the same degree as that of the manured plots. The second nine inches was also very much altered from the character of the clay subsoil. Below this point very slight difference was observable, though the next, the third from the surface, perhaps showed slightly the least, and the lowest or sixth depth the most, of the bright clay tinge.

In the soil of the plot manured with the mineral manure and ammonia-salts the roots did not appear to penetrate much deeper than in that of the unmanured, but they were in greater quantity and of larger size. The first nine inches of soil was perhaps rather darker, and more mould-like; the second nine inches was decidedly more changed by vegetation than that of the unmanured plot, and the third and fourth were slightly so. The fifth and sixth were little distinguishable in colour from the raw reddish-yellow clay of the unmanured plot at corresponding depths.

The first and second nine inches of the soil of the nitrate-plot showed but little difference compared with those manured with ammonia-salts. The third, fourth, fifth, and sixth nine inches were, however, very different in appearance from the corresponding layers of either of the other plots, the clay being much mottled or veined, and when the samples were powdered they were of a yellowish-grey instead of reddish-yellow colour, and the lighter or less red the greater the depth. In the samples taken in 1876 the distinctions were by no means so marked; but still the subsoils of the nitrate-plot showed in the second, third, fourth, and fifth depths, a lighter, yellower, and less red tinge.

The percentage of nitrogen in the different soils, at the different depths, will be recorded and considered in detail further on; but it will be of interest briefly to notice the general bearing of the results in this place. Although the percentages (determined by soda lime) in the samples collected after a lengthened continuance of the drought in 1870 differ in some respects from those on the samples of 1876, the two series agree in showing, at every depth, a higher percentage on the ammonia-plot than on the unmanured, and, with one slight exception which may be accidental, a lower percentage in the soils of the nitrate than in those of the ammonia-plot, especially in the lower layers, where it is lower also than in the case of the unmanured plot, and indeed than in that of the majority of the other plots.

That the upper layers of the soil of the ammonia-plot should show higher percentages of nitrogen than those of either of the other plots is consistent with the fact that the nitrogen of ammonia-salts is, in the first instance, in a great degree arrested in the upper layers of the soil, and is so, much more than is that of nitrate of soda; and that the percentage should be also higher in the lower depths than without manure indicates, presumably, a gradual percolation of the supplied nitrogen in some form. With the rapidly distributing nitrate of soda, and with it the more deeply penetrating roots, there is, on the other hand, a less accumulation of nitrogen, not only in the upper but in the lower layers; and that the percentage should decrease so rapidly in the lower layers is probably partly due to passage upwards in dry, and, in greater measure, drainage downwards in wet, weather. Thus, it has been shown that in the drought more water passed upwards from the lower layers, and it would doubtless carry with it nitrate in solution; and with the greater solubility of the nitrate, and the greater disintegration, and consequently greater permeability of the subsoil under its influence, the loss of the supplied nitrogen by drainage would be the greater. Lastly, that the percentage of nitrogen in the lower layers should be even less in the case of the nitrate than of the unmanured plot may perhaps be partly due to more rapid oxidation, and more easy percolation and loss by drainage, of the nitrogen of previous accumulations, in the more disintegrated and more porous subsoil.

The main distinctions in the flora on plot 14 with the nitrate and plot 9 with the ammonia-salts are, that with the nitrate there was more, and an increasing amount, of *Alopecurus*, very much more *Bromus mollis* and *Poa trivialis*, and more of *Lolium perenne;* but, on the other hand, there was very much less *Poa pratensis* and *Festuca ovina*, much less *Agrostis*, and upon the whole less *Holcus*, with, in all, more total Gramineæ.

On neither plot is there, on the average of seasons, anything like 1 per cent. of leguminous herbage in the produce; but there is more on the plot with the nitrate than on that with the ammonia-salts.

Of herbage referable to other orders, the ammonia-salts have generally yielded more than the nitrate, but latterly not so much. The most prominent of these plants under the influence of the ammonia-salts is *Rumex acetosa;* next in order comes the *Conopodium denudatum*, and then the *Achillea millefolium;* others occurring in quite immaterial amounts. The chief of those developed on the nitrate-plot are, again, *Rumex acetosa*, and, in somewhat equal and increasing amount, *Anthriscus sylvestris*, the *Achillea millefolium* and *Conopodium denudatum* coming next in order, but each in less quantity than with the ammonia-salts. All others are in insignificant amount, but *Taraxicum officinale* occurs more plentifully than on plot 9.

With 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, accordingly as the nitrogen is applied as ammonia-salts or as nitrate of soda, it will be of interest briefly to call attention to the chief differences in the chemical composition of the produce.

As shown in Table XII., 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 potass, and very much less chlorine, taken up.

It has been before observed that, with an increased amount of soda applied in the manure, more was taken up and retained—a result which would be more marked in the case of imperfectly ripened vegetable matter, like hay, than in that of fully ripened products, such as cereal grain. It has also been observed that when there was an increased fixation of silica, it was generally in association with an increased amount of soda rather than of potass taken up. It was strikingly so in the case of the produce of plot 14. Thus, besides the much greater accumulation of soda which was so liberally applied, the plants growing under the influence of the nitrate accumulated not only more of each of the other mineral constituents (except potass) which were equally supplied to both plots, but more also of silica which was not supplied to either. This obviously indicates possession by the roots of the growing herbage of a greater range of soil and subsoil, and is consistent with the facts which have been pointed out as to the character of the root development, and the altered condition of the subsoil, under the influence of the nitrate of soda.

Since the produce grown by the mineral manures and nitrate was riper when cut than that by the mineral manures and ammonia-salts, a somewhat lower percentage in the dry substance, of potass, as well as of other constituents, would be expected; and it might merely indicate a greater accumulation of organic matter at the maturing period, by which, obviously, the percentage in the dry substance of the already accumulated mineral matter would be reduced. Such reduction is known to be the general accompaniment of favourable maturation. But here, the percentage of potass in the dry substance of the produce grown by the nitrate was, taking the average of the 18 years, only about four-fifths as much as in that grown by the ammonia-salts. This reduction is probably greater than can be accounted for merely by a greater accumulation of organic matter during the maturing period. Indeed, there was, not only a lower percentage, but, as already mentioned, a notably less actual amount per acre, of potass fixed under the influence of the nitrate, though it was equally supplied to both plots, and though the herbage was even more gramineous, and more stemmy—a result which is certainly somewhat remarkable. And although there was at the same time much more soda taken up, and the excess was more than equivalent to the actual deficiency of potass per acre, it was not sufficient to compensate for the deficiency of potass per cent. in the dry substance.

In connexion with these results, showing a greater amount of produce by the use of a given amount of nitrogen as nitrate of soda than as ammonia-salts, an increasing instead of a decreasing produce in the later years, a greater independence of drought, and a greater disintegration, increasing the porosity of the clay subsoil, it may be well to refer to some results obtained in experiments with barley. In the field at Rothamsted which is now (1879) growing the twenty-eighth crop of barley in succession, two plots received, in the first season, equal amounts of mineral manure; but in the second, third, fourth, fifth, and sixth years, the one received 550 lbs., and the other 275 lbs., of nitrate of soda per acre per annum. From that time up to the present, each has received only 275 lbs. per acre per annum. Yet, with one exception, in each of the 21 succeeding years, the plot to which the double amount of nitrate had previously been applied has yielded more produce; and in the twentieth year since the double application (1877), it yielded $3\frac{3}{4}$ bushels more corn, and $3\frac{1}{4}$ cwts. more straw, per acre. The excess of yield has also been more marked in the drier seasons. The soils and subsoils of these two plots have not been examined. But, judging from the results which have been described, the question suggests itself—whether the explanation be not that where the excessive amount of nitrate was applied in the earlier years, the subsoil was so acted upon, disintegrated, and rendered more porous, that it offered a greater surface for the retention of the otherwise easily washed-out nitrate, a greater surface for the retention of moisture, and greater permeability to the roots; thus increasing the store, both of available food and available moisture, at command of the plant, and facilitating the penetration of the roots in search of them?

To conclude, in regard to the greater effects of a given amount of nitrogen as nitrate of soda than as ammonia-salts when applied to the mixed herbage of grass land: it is obvious that the result is dependent on a great variety of circumstances. The nitrogen of the nitrate distributes much more rapidly through the soil and subsoil. The flora becomes greatly modified. Plants of different habits, both of aboveground and underground growth, are developed. Accordingly, the roots obtain possession of different ranges of soil and subsoil; and according to their range, and to their functional capability of food-collection, they gather up the more. With these favourable soil-conditions, the plant takes up more from the atmosphere within a given time. But, how far it does so simply as a result of a more favourable condition of the cell and sap, due to a more favourably balanced supply of nitrogenous and mineral food, inducing greater activity of a given leaf-surface, or how far it is that, conjointly with greater vegetative activity, there is, as there necessarily must be, also a constantly increasing above-ground surface, and hence a complex and cumulative action, is a question beyond the scope of our observed facts to determine. That the increased assimilation of carbon over a given area cannot be entirely accounted for by the supposition that the particular species of plants developed have a greater assimilative power for a given leaf-surface than those they have replaced, would appear from the fact that, when a given amount of nitrogen, as nitrate of soda and ammonia-salts respectively, is applied for one and the same description of crop—barley, for example—there is also found a greater fixation of carbon—that is more growth over a given area—under the influence of the nitrate.

11. 275 *lbs. Nitrate of Soda, with Mixed Mineral Manure, containing Potass; Plot* 16.

The next selection of results shows the effects of the mixed mineral manure with only 275 lbs. of nitrate of soda per acre per annum; that is, only half as much as was applied on plot 14, and containing, of course, only half as much nitrogen as the ammonia-salts on plot 9. This experiment was made on plot 16, and as in the case of the other nitrate plots it did not commence until 1858, so that, as before, we give the average results for only 8, 10, and 18 years; and for comparison those of plot 14 for the same periods are again brought forward.

TABLE XIV.—Average, per acre per annum, by 275 lbs. Nitrate of Soda, with Mixed Mineral Manure, containing Potass; Plot 16.

	Average per acre per annum.		
	Plot 14. Mineral manure and 550 lbs. nitrate soda.	Plot 16. Mineral manure and 275 lbs. nitrate soda.	Plot 16 + or − plot 14.
HAY.			
	lbs.	lbs.	lbs.
First period, 8 years, 1858–1865	5944	5058	− 886
Second period, 10 years, 1866–1875	6777	5332	−1445
Total period, 18 years, 1858–1875	6407	5210	−1197
Second period, per cent. + or − first period	+14·0	+5·4	
NITROGEN.			
First period, 8 years, 1858–1865	67·6	63·0	− 4·6
Second period, 10 years, 1866–1875	70·6	62·4	− 8·2
Total period, 18 years, 1858–1875	69·3	62·6	− 6·7
Second period, per cent. + or − first period	+ 4·4	−1·0	
MINERAL MATTER (ASH).			
First period, 8 years, 1858–1865	357·2	320·9	− 36·3
Second period, 10 years, 1866–1875	373·2	307·9	− 65·3
Total period, 18 years, 1858–1875	366·1	313·7	− 52·4
Second period, per cent. + or − first period	+ 4·4	−4·1	

There was no plot with the mixed mineral manure and ammonia-salts in quantity containing only as much nitrogen as 275 lbs. of nitrate of soda. The main comparison must, therefore, be made with double the amount of nitrate (plot 14).

As with the double so with the single amount of nitrate (and the mineral manure), there was an average of more produce of hay over the last 10, than over the first eight of the 18 years. But, on the other hand, there is not, as there was with the double quantity, a greater average annual amount of nitrogen and of mineral matter removed over the second period. There was, however, only a slight deficiency; and, what is more remarkable, there is, over the 18 years, an average of only about 6½ lbs. less nitrogen annually removed than where the double amount of nitrate, supplying annually about 41 lbs. more nitrogen, was applied.

On both plots, 14 and 16, *Alopecurus pratensis* is plentiful and increasing. With the mineral manure and the smaller quantity of nitrate (plot 16) there was a larger proportion of *Holcus lanatus,* and much more of *Avena flavescens, Agrostis vulgaris,* and *Festuca ovina,* especially of the two latter; but there was a smaller proportion of *Lolium perenne,* considerably 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, however, 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; more *Ranunculus,* both *acris* and *bulbosus,* more *Conopodium denudatum,* more *Achillea millefolium,* and more *Rumex acetosa,* but much less *Anthriscus* than on 14.

In fact, on plot 16, with the smaller amount of nitrate, a greater variety of grasses contributed the bulk of the produce, but there was a less proportion of the more freely-growing species. The herbage was made up in considerably less proportion of Gramineæ, and it contained both a greater number of species, and a considerably greater percentage by weight, of those belonging to the leguminous and other orders.

As already mentioned, the average percentage of mineral matter in the dry substance is highest in the miscellaneous, lower in the leguminous, and lowest in the gramineous herbage. The dry matter of the gramineous herbage, again, contains the lowest average percentage of nitrogen, that of the miscellaneous a higher, and that of the leguminous much the highest. Hence, we should expect a higher percentage of both mineral matter and nitrogen in the dry substance of the less gramineous mixed herbage grown by the smaller amount of nitrate, and this is actually found. And, as the leguminous, and to some extent the miscellaneous herbage also, seems less influenced by, and less dependent on, artificial supply of nitrogen, the greater yield of nitrogen in proportion to that applied in manure may not indicate the utilisation of a correspondingly larger proportion of that supplied, but only that more has been gathered from natural sources.

It is obvious that, with a greater number of species, comprising those belonging to very characteristically different orders, the representatives of which have widely different habits of growth, not only above but underground, there will be a greater variety of root-distribution, a greater variety in food-collecting capacity, and probably, with these, a greater total capability of such collection. There is, accordingly, a higher percentage of lime, an equal percentage of magnesia, a considerably higher percentage of potass 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, potass, 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.

It has before been shown, that a given amount of nitrogen applied as nitrate of soda gave more produce than the same amount applied as ammonia-salts, whether these nitrogenous manures were respectively used alone, or in conjunction with a mixed mineral manure supplying in excess all the mineral constituents of the crop, except silica. It was also shown that, when used alone—that is to say, when the whole of the mineral constituents (except soda) had to be obtained from the soil itself—275 lbs. of the nitrate yielded nearly as much produce, containing more of some, and nearly as much of all, of the mineral constituents, as when 550 lbs. were employed.

It is now seen that, when used in each case in conjunction with the mixed mineral manure, the smaller amount of nitrate does not give nearly so large an actual amount of produce as the larger; but the smaller amount does give a greater produce of hay, and a greater yield of nitrogen in the crop, for a given amount of nitrate used. Thus, with the mineral manure and the larger amount of nitrate there was, over the 18 years, an average per acre per annum, of about 57 cwts. of hay, containing a little over 69 lbs. of nitrogen; and with the smaller amount of nitrate there was an average of 46½ cwts. of hay, containing about 62½ lbs. of nitrogen. This larger yield for a given amount of nitrate used, was associated with, and doubtless greatly dependent on, the much greater complexity of herbage than when the more forcing excessive amount was employed. The herbage of plot 16, with the mineral manure and the smaller amount of nitrate, was, indeed, more complex than that of any other plot yielding the same weight of hay; its gramineous herbage was in a less degree made up of a few very freely-growing grasses; it contained a considerable and an increasing amount of leguminous herbage—much more than in the other cases with an equal amount of crop; and finally, it contained a large number, and a considerable percentage by weight, of miscellaneous species. 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, as a rule, the more complex the herbage, the higher 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, we have 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 *lbs. Ammonia-Salts, and Superphosphate of Lime; Plot* 4–2.

In the experiments hitherto considered in which nitrogenous and mineral manures have been used together, the mineral manures have consisted of a complex mixture, in some cases supplying an excess of all the mineral constituents of the crop except silica, and in some including silica. We have yet to consider the comparative effects of a given amount of nitrogenous manure, 400 lbs. ammonia-salts—when used alone (plot 5); when in conjunction with superphosphate of lime alone (plot 4–2); with superphosphate of lime, and salts of soda and magnesia, without potass (plot 10); and when with superphosphate of lime, salts of soda and magnesia, and potass also (plot 9).

The first comparison will be between ammonia-salts alone, and in conjunction with superphosphate of lime, plots 5 and 4–2; and as the experiment with the superphosphate did not commence until the fourth year, the periods selected are 7, 10, and 17 years.

TABLE XV.—Average, per acre per annum, by 400 lbs. Ammonia-Salts, and Superphosphate of Lime; Plot 4–2.

	Average per acre per annum.		
	Plot 5. Ammonia-salts, alone.	Plot 4–2. Ammonia-salts, and superphosphate.	Plot 4–2 + or − plot 5.
HAY.			
	lbs.	lbs.	lbs.
First period, 7 years, 1859–1865	3202	4440	+1238
Second period, 10 years, 1866–1875	2471	3414	+ 943
Total period, 17 years, 1859–1875	2772	3837	+1065
Second period, per cent. + or − first period	−22·8	−23·1	
NITROGEN.			
First period, 7 years, 1859–1865	56·0	67·6	+11·6
Second period, 10 years, 1866–1875	47·3	57·8	+10·5
Total period, 17 years, 1859–1875	50·9	61·8	+10·9
Second period, per cent. + or − first period	−15·5	−14·5	
MINERAL MATTER (ASH).			
First period, 7 years, 1859–1865	163·0	250·0	+87·0
Second period, 10 years, 1866–1875	108·9	162·3	+53·4
Total period, 17 years, 1859–1875	131·2	198·3	+67·1
Second period, per cent. + or − first period	−33·2	−35·1	

Over the 20 years, ammonia-salts alone gave about one-fourth more produce than was obtained without manure; and the results quoted above show that, over the 17 years of the comparative trial, the mixture of ammonia-salts and superphosphate of lime gave more than one-third more produce than the ammonia-salts alone. Superphosphate of lime alone, however, gave scarcely any more produce than that without manure, doubtless owing to a deficiency of nitrogen available to such plants as were developed. But when the ammonia-salts were used alone, there was obviously, on the other hand, a deficiency of mineral supply for the amount of available nitrogen. The superphosphate of lime, supplying as it did, besides a considerable excess of phosphoric acid, also an excess of sulphuric acid and lime, and some magnesia, remedied this so far; but, as will be seen from the next comparisons, there was still a considerable deficiency of some other mineral constituent, or constituents, necessary to give anything like full effect to the amount of nitrogen supplied in the ammonia-salts.

The figures show that there was, not only much more total produce, but also much more nitrogen and total mineral matter annually removed, when the superphosphate as well as the ammonia-salts was used; but that, notwithstanding the different actual amounts of yield, there was, under the two conditions of manuring, very nearly the same percentage reduction in yield of hay, of nitrogen, and of mineral matter, over the last 10 compared with the first seven years. There is thus indicated the influence of a larger supply of mineral matter, but at the same time an almost equal rate of decline in the amount available as the experiment proceeded. Calculation of the analytical results shows, however, that the increase in the amount of total mineral matter removed under the influence of the addition of superphosphate was considerably greater than was represented by the increased amount taken up of those mineral constituents which it supplied—namely, lime, magnesia, phosphoric acid, and sulphuric acid. There was also more potass, in a greater proportion more soda, and more silica, taken up—all of which must have been supplied by the soil itself. It has before been pointed out that the produce by ammonia-salts alone removed even less potass than that without manure—a fact supposed to be explained by the greater root-range of the much more varied flora of the unmanured plot; and although the addition of superphosphate to the ammonia-salts causes the removal of considerably more potass, there is still not much more removed than without manure. There was, too, a very great decline in the average annual amount taken up of almost every mineral constituent over the second period compared with the first; the exceptions being 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, and the more so where the superphosphate of lime was also used. On both, the Leguminosæ nearly disappeared, and, again, the more so where the superphosphate of lime was employed. On both, the miscellaneous herbage much declined, excepting that the *Rumex acetosa* was in some seasons very prominent. With the superphosphate and the greater predominance of the grasses, the number of species also declined more than with the ammonia-salts alone.

On both plots the *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* was the next in order of predominance, and has also gradually increased, 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 plot with the ammonia-salts and superphosphate, *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.

Thus, not only did the herbage 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, but especially the *Festuca ovina,* 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 *lbs. Ammonia-Salts, and Mixed Mineral Manure, with and without Potass; Plots* 9 *and* 10.

The next table compares the results obtained on plots 9 and 10. During the first six years of the 20 both received annually 400 lbs. of ammonia-salts, and the "mixed mineral manure," including potass. The only difference was that plot 10 received also 2000 lbs. of 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 potass was omitted from the manure of plot 10, and a somewhat increased amount of sulphate of soda was applied instead. The table shows the average produce of hay, and its contents of nitrogen and mineral matter, over the first six years when both plots were manured alike (excepting the sawdust on plot 10); over the next 14 years during which the potass was still applied to plot 9, but omitted on plot 10, and over the total period of 20 years.

TABLE XVI.—Average, per acre per annum, by 400 lbs. Ammonia-Salts, and Mixed Mineral Manure, with and without Potass; Plots 9 and 10.

	Average per acre per anunm.		
	Plot 9. With potass 20 years.	Plot 10. With potass 6 years, without 14 years.	Plot 10 + or − plot 9.
HAY.			
	lbs.	lbs.	lbs.
First period, 6 years, 1856–1861	6349	6223	− 126
Second period, 14 years, 1862–1875	5438	4725	− 713
Total period, 20 years, 1856–1875	5711	5174	− 537
Second period, per cent. + or − first period	−14·3	−24·1	
NITROGEN.			
First period, 6 years, 1856–1861	78·7	73·3	− 5·4
Second period, 14 years, 1862–1875	70·9	72·7	+ 1·8
Total period, 20 years, 1856–1875	73·2	72·9	− 0·3
Second period, per cent. + or − first period	− 9·9	− 0·8	
MINERAL MATTER (ASH).			
First period, 6 years, 1856–1861	406·8	419·8	+13·0
Second period, 14 years, 1862–1875	303·7	243·8	−59·9
Total period, 20 years, 1856–1875	334·6	296·6	−38·0
Second period, per cent. + or − first period	−25·3	−41·9	

Of hay, the average produce per acre per annum over the 20 years was—without manure, 2383 lbs.; with ammonia-salts alone, 2946 lbs.; with ammonia-salts and superphosphate of lime (17 years), 3837 lbs.; with ammonia-salts and mixed mineral manure, with potass for six years and without potass 14 years, 5174 lbs.; and with ammonia-salts and the mixed mineral manure, including potass every year, 5711 lbs.

The table shows that, even where the application of sulphate of potass was continued, there was a falling off of annual produce amounting to 14·3 per cent. over the last 14 compared with the first six years. But where the potass was discontinued there was a falling off, over the same period, of 24 per cent.

It is remarkable that there was, over the 20 years, almost identically the same amount of nitrogen taken up where the potass was discontinued as where it was continuously applied, and during the period of the omission there was even rather more. There was, moreover, scarcely any reduction in the amount taken up over the second period compared with the first. Indeed, the greater average yield of nitrogen over the whole period in the produce with the more potass applied is due to the greater amount taken up during the earlier years, when both plots were practically manured alike. In regard to the even lower amount with than without the potass over the later period, it should be observed that the potass-plot (9) has probably suffered at one end, for some years, from the roots of a large tree, but to what extent it is difficult to say.

Of mineral matter, on the other hand, about one-fifth less has been taken off, over the 14 years, in the crop grown without than with potass; and the falling off in amount, compared with the earlier period, is nearly 42 per cent. without, against only 25 per cent. with, the potass.

Thus, notwithstanding there was even rather more nitrogen annually taken up on plot 10 over the 14 years during which the potass was excluded from the manure, there was much less hay produced, and much less mineral matter taken up, than on plot 9, where the application of potass was continued. There was an average annual deficiency of more than 700 lbs. of hay, and of about 60 lbs. of mineral matter; the former representing a deficiency of carbon assimilated averaging about 230 lbs. per acre per annum in the removed produce, to say nothing of the second crops, the roots, &c.

The deficiency of total growth on plot 10 compared with plot 9 was not manifested in any marked degree until after the first five years of the 14; in fact, during the first six years of the 20, a total of about 900 lbs. of potass per acre had been applied to each plot, and the total amount taken out in the crop was much less than this. It is to be supposed, therefore, that there was a considerable residue of the supplied potass possibly available for the succeeding crops. How much, however, it is impossible to decide absolutely; for, in the first place, we do not know whether as much, or more, or less, was given up from the soil itself in the presence of the liberal artificial supply than was taken up without manure, or by the ammonia-salts alone, or by the ammonia-salts and superphosphate of lime without potass or soda; nor, in the second place, do we know how much of the residue of the supplied potass would enter into such combinations within the soil as to remain either unavailable, or but slowly available to succeeding crops.

If we assume, by way of illustration, and as as probable an estimate as we are able to make, that the soil of plot 10, during the six years when it received ammonia-salts and mixed mineral manure containing potass, yielded up to the growing crop the same quantity from its own stores as plot 4–2 during the first six years in which it received the same quantities of ammonia-salts and superphosphate of lime, but without potass or soda, then the residue of potass supplied during the six years to plot 10 would be about 412 lbs. at the end of that period. Yet, there was a very marked deficiency of potass taken up on plot 10 compared with plot 9 even in the first year of the discontinuance of the application. But there was, on the other hand, a very marked increase in the amount taken up compared with that on plot 4–2, with the ammonia-salts and superphosphate only; and that increase continued, though diminishing, throughout the 14 years. And if, as above supposed, there were 412 lbs. residue of supplied potass within the soil at the commencement of the 14 years, and during those years the soil itself still yielded up as much as during the same period on plot 4–2, which had not received potass at all, there would still remain to be accounted for more than 200 lbs. of the supplied potass at the end of the 14 years; and it may be observed that, in each of the three succeeding years (1876–77–78), plot 10 gave considerably more produce than plot 4–2.

It would appear, therefore, that there was a considerable residue of potass 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 14 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 potass applied 25 years or more previously. Supposing, however, that in the presence of an artificial supply of potass less was yielded up from the soil itself, the residue remaining would of course be by so much less than 200 lbs. at the end of the 14 years.

About an equal number of species, and nearly the same species, were represented on the two plots 9 and 10—the one with the continuous, and the other with the temporary supply of potass; but on neither was the total number much more than half as many as without manure. As on plots 5 and 4–2, the one with ammonia-salts alone, and the other with ammonia-salts and superphosphate, so now when, with these, salts of potass, soda, and magnesia, are also used, the herbage has become more and more, and very prominently, gramineous. But whilst without the alkali-salts, in the later years about 80 per cent. of the total produce was made up of two grasses, yielding a stunted, dark-green, and almost exclusively leafy, herbage, with them the produce was very much more mixed, and the bulk was made up of many more grasses, few of which are in undue prominence.

Thus, the six grasses which have of late years become the most prominent on plot 9, with, besides the other manures, an excess of potass every year, are (and 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. Again, the seven which have become, or remain, the most prominent on plot 10, with the discontinued supply of potass, are—*Festuca ovina, Agrostis vulgaris, Alopecurus pratensis, Avena elatior, Poa pratensis,* and (in a less degree than any of the six on plot 9) *Holcus lanatus,* and *Dactylis glomerata,* which together make up about as much as the six on plot 9. The chief differences between the two plots 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 most on plot 10. On the other hand, *Avena pubescens, Avena flavescens, Poa trivialis, Bromus mollis,* and *Lolium perenne* have almost disappeared on both plots.

On both plots leguminous species are represented by only a small fraction of 1 per cent. of the total produce, and by less on plot 10 than on plot 9.

Miscellaneous species also have considerably decreased, and more in weight than in number, on both plots—and again the most on plot 10; excepting that the *Rumex acetosa,* which is the most, and very, prominent on both, is upon the whole the more prominent on plot 10. Next, but in much less quantity, come the *Conopodium denudatum,* and the *Achillea millefolium,* both of which are much declining, but are somewhat more prominent on plot 9 than on plot 10.

Thus, there was considerable similarity in the number and description of species on the two plots, and some, but less, in the proportion by weight of individual species; whilst, the weight per acre of total gramineous herbage was much less, and that of both the leguminous and the miscellaneous was also the less, on plot 10. The character of development also was extremely different. On plot 9, with the continuous supply of potass, the grasses showed much tendency to produce stem and seed, and to mature. On plot 10, on the other hand, with the only temporary supply of potass, 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 potass a deficient assimilation of carbon.

With these great differences in the character of development apparent to the eye, there were corresponding differences in the chemical composition quite consistent with them and their cause.

In the dry substance of the produce grown with the deficient supply of potass there was a considerably higher, and an abnormally high, percentage of nitrogen, and a lower percentage of total mineral matter. There was a considerably higher percentage of lime, magnesia, phosphoric acid, and sulphuric acid; a quadruple percentage of soda; with this a considerably increased percentage of silica, and at the same time a very greatly increased percentage of chlorine. There was, on the other hand, in the dry substance of this leafy, highly nitrogenous, and immature produce, over the average of the 14 years, considerably less than half as high a percentage of potass as in that where it had been more liberally supplied, and where the herbage was better developed and more matured.

The actual amounts taken up per acre over the 14 years were, of lime, magnesia, phosphoric acid, sulphuric acid, and silica, much the same on the two plots; of chlorine one-and-a-half time, and of soda three-and-a-half times as much was taken up on plot 10, but of potass little more than one-third as much on plot 10 as on plot 9.

It will be of interest briefly to compare the results obtained on these plots, 9 and 10, with those on plots 7 and 8, on both of which the same "mixed mineral manure," including potass, was also applied during the first six years; then the same was continued on one plot (7), and the same, excluding potass, on the other plot (8), for the next 14 years. But whilst ammonia-salts were liberally applied equally to plots 9 and 10 throughout the whole period of 20 years, no nitrogenous manure was applied to plots 7 and 8.

On the plots with the ammonia-salts there was, both with and without the continuous supply of potass, much more produce, and much more nitrogen and mineral matter taken up, than on the corresponding plots without nitrogenous manure.

With the continuous supply of potass there was, when used with ammonia-salts, a considerable reduction in the produce over the later years; but when without the ammonia there was even a slight increase.

Where the application of potass was discontinued over the later period there was, both with and without the nitrogenous manure, a considerable reduction in the yield of hay over that period; but whilst with the nitrogenous manures there was no reduction in the amount of nitrogen taken up, there was, where there was no artificial supply of nitrogen, a reduction of about one-third in the amount of it taken up, in that case from natural sources, due to the discontinuance of the application of potass.

Both with and without the ammonia-salts the exclusion of the potass caused a great reduction in the amount of mineral matter taken up, and a greater, both actually and proportionally, where the ammonia-salts were used.

On the plots with ammonia, both with the continuous and the temporary supply of potass, the produce was chiefly gramineous, contained scarcely any leguminous herbage, but few prominent miscellaneous species, and the flora of the plot was not very materially affected by the discontinuance of the potass; but, without the potass, the gramineous herbage showed very different, and much inferior, characters of development. Without ammonia, on the other hand, and with the potass, the produce contained a large proportion of leguminous herbage; and the most prominent effect of the discontinuance of the potass 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.

Thus, there were very different amounts of produce, and the botanical character of the herbage was very different, accordingly as the mixed mineral manure, including potass, was employed with or without nitrogenous manure; and when the application of potass was stopped, the effect on the botany of the plots was, in some important respects, very different. Notwithstanding this, the effect of the exclusion of the potass was, both with and without ammonia, immediately and greatly to reduce the amount of potass taken up (and more or less that of some other constituents), and by degrees greatly to reduce the amount of produce also.

We have in these comparisons remarkably consistent and cumulative evidence of the importance of a liberal available supply of potass within the soil if we would grow large, properly-developed, and well-matured, hay crops. With a fairly mixed herbage, and only moderate nitrogenous manuring, a liberal supply of potass 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 potass will much diminish the amount of produce, and consequently the efficiency of the nitrogenous manure, and it will, moreover, lead to a deterioration in the character of the growth.

14. *Mixed Mineral Manure alone* 7 *years; succeeding Ammonia-salts alone* 13 *years; Plot* 6.

The results next quoted will illustrate the effects of applying the mixed mineral manure, including potass, for seven years in succession on a plot which had received ammonia-salts, without mineral manure, in each of the 13 preceding seasons (with sawdust in addition the first seven years). The experiment was made on plot 6; and, for comparison, the average results, over the same 13, 7, and 20 years, are given—for plot 5, which received the same quantity of ammonia-salts (without sawdust) in each of the 20 years, as were applied to plot 6 during the first 13 years; and for plot 7, which received the same mixed mineral manure throughout the 20 years, as plot 6 received during the last seven years.

TABLE XVII.—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.					
	lbs.	lbs.	lbs.	lbs.	lbs.
First period, 13 years, 1856–1868	3317	3425	3914	+ 108	−489
Second period, 7 years, 1869–1875	2257	3502	4040	+1245	−538
Total period, 20 years, 1856–1875	2946	3452	3958	+ 506	−506
Second period, per cent. + or − first period.	−32·0	+2·2	+3·2		
NITROGEN.					
First period, 13 years, 1856–1868	57·8	59·1	56·9	+1·3	+ 2·2
Second period, 7 years, 1869–1875	43·0	41·9	55·9	−1·1	−14·0
Total period, 20 years, 1856–1875	52·6	53·1	56·6	+0·5	− 3·5
Second period, per cent. + or − first period.	−25·6	−29·1	−1·8		
MINERAL MATTER (ASH).					
First period, 13 years, 1856–1868	171·8	175·6	254·5	+ 3·8	−78·9
Second period, 7 years, 1869–1875	95·4	189·2	252·8	+93·8	−63·6
Total period, 20 years, 1856–1875	145·1	180·4	254·0	+35·3	−73·6
Second period, per cent. + or − first period.	−44·5	+7·7	−0·7		

The sawdust applied on plot 6 during the first seven years being of little or no effect, the two plots, 5 and 6, each annually receiving the same quantity of ammonia-salts, were practically duplicates. On both, the produce was gradually diminishing, or in other words the effects of a given amount of nitrogen supplied was decreasing, and the character of the herbage was very greatly deteriorating. Hence, after 13 years, it was decided to continue the application of ammonia-salts alone on one plot only (5), to discontinue it on the other (plot 6), and to apply to it the mixed mineral manure, including potass, instead. The objects sought in the change were—to determine its effects, not only on the amount of produce, but on the character of the herbage, both as to the description of species developed, and the character of development, also on the chemical composition of the produce; 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 mineral manuring?

The table shows that whilst with the ammonia-salts alone every year the average annual produce of hay was nearly one-third less over the last seven than over the first 13 years, it was even rather higher over the last seven years than over the previous 13, where (on plot 6) the mixed mineral manure had been substituted for the ammonia-salts. Still, the amount of produce did not nearly reach that yielded on plot 7, where the same mixed mineral manures had been applied every year of the 20.

In the amount of nitrogen annually taken off there was a considerable reduction over the last seven compared with the first 13 years, both where the application of the ammonia-salts was continued, and where the mixed mineral manure was substituted. But it is significant that there was nearly as much annually taken up where the application of ammonia-salts had been stopped, and mineral manures applied instead, as where the ammonia-salts were still applied. In neither case, however, was there as much nitrogen taken up as over the same seven years where no nitrogenous manure, but the mixed mineral manure alone, had been applied from the commencement.

The reduction in the amount of mineral matter annually taken off was, where the ammonia-salts were continuously applied, very much greater than that of either the hay or the nitrogen. On the other hand, where the mineral manures were substituted there was even rather more mineral matter taken up over the seven years of their application than previously. But, as in the case of the produce yielded, and of the nitrogen removed, so also in that of the mineral matter, there was much less annually taken up than where the same mineral manures had been annually applied over the whole period.

With regard to the nearly equal amount of nitrogen taken up where the mineral manures succeeded the ammonia-salts, as where the nitrogenous manure was still applied, the question suggests itself—whether the result was merely due to the gathering up by the herbage already prevalent, of the unexhausted residue of the nitrogen of the previous applications—or, whether to the development of different plants, having more extended root-ranges, or different powers of collection from natural sources? For certainly it was due to the latter causes that where, as on plot 7, mineral without any nitrogenous manures were applied every year, there was yet yielded, over the 20 years, even rather more nitrogen in the produce than was obtained on plot 5, where 82 lbs. of nitrogen were applied per acre annually. It will be remembered that the surface-soil of the continuously mineral-manured plot showed a lower percentage of nitrogen than that of the continuously unmanured plot, indicating the source whence the increased yield of nitrogen in the mineral manured complex herbage had been derived.

The data at command do not enable us to give a decisive answer on these points, but it will be of interest briefly to notice the facts bearing upon them.

In the first place, not quite three-fourths as much nitrogen was taken off in the total produce of plots 5 and 6, during the 13 years of the application of the ammonia-salts to both, as was contributed by the manure during that period. And if we deduct from the nitrogen in those crops the amount obtained during the same period in the produce without manure, the so reckoned *increased* amount taken off, due to the action of the ammonia-salts, would be little more than one-fourth of that supplied. Again, during the last seven years of the 20, little more than half instead of three-fourths as much nitrogen was removed in the total produce of plot 5 as was supplied in the ammonia-salts during that period; or if as before we deduct the amount taken up without manure, less than 20 per cent. of that supplied would appear to have been recovered.

We have then, according to the mode of reckoning, from one-fourth to three-fourths of the supplied nitrogen unrecovered in the crops during the 13 years; and, as already intimated, there was almost identically the same amount of nitrogen taken up during the next seven years from plot 6, where the application of the ammonia-salts was stopped and mineral manures were applied instead, as on plot 5, where the application of the ammonia-salts was continued. Still, the total amount of nitrogen taken off in the produce of plot 6, over 20 years, was scarcely as much as had been supplied during the first 13 years, and if the yield without manure be deducted, more than 60 per cent. of that supplied during the 13 years remained unrecovered as increase in the 20 years.

Determinations of nitrogen, made by the soda-lime method, in the soils and subsoils of the unmanured plot 3, and of the continuously ammonia-manured plot 5, after the 20 years, did indicate some accumulation of nitrogen, so determinable, in the soil and subsoils of the ammonia-plot, down to the depths examined, namely, 54 inches, but far from sufficient to account for the otherwise unrecovered amount of supplied nitrogen; and, judging from somewhat parallel cases, it would be concluded that at any rate some would be retained by the soil and subsoil in an only slowly available condition, but that a considerable proportion of the supplied ammonia would be oxidated, and pass away in the drainage, as nitrites and nitrates, beyond the reach of the roots.

It would thus appear probable that after the 13 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. But that as much was taken up as where the ammonia-salts were still annually applied would seem to require some further explanation.

In reference to this point we have the significant fact, as will be fully illustrated further on, that the surface soil of plot 6 showed at the end of the 20 years—that is, after the mineral manures had been applied for seven years—a notably lower percentage of nitrogen than the corresponding layer of plot 5; thus pointing to a source of nitrogen to the plants similar to that which is supposed to have contributed to the high nitrogenous yield of plot 7, where the mineral manures alone, including potass, had been applied throughout the 20 years. It remains to consider whether, not only the conditions of manuring, but the characters of the vegetation, were also consistent with, in great measure, a similar source of nitrogen in the two cases.

It will be remembered that on plot 5, with ammonia-salts alone, the herbage became more and more gramineous, contained scarcely any leguminous plants, and, with the exception of *Rumex acetosa*, very little of any miscellaneous species. The grasses became patchy, stunted, very dark-green, and almost exclusively leafy; and in the later years the two species, *Festuca ovina* and *Agrostis vulgaris*, contributed more than four-fifths of the total produce. In the first year of the substitution of the mixed mineral manure, including potass, for the ammonia-salts (on plot 6), the appearance of the plot entirely changed. Although *Festuca ovina* and *Agrostis* were still very prominent, several other grasses began to assert themselves; and now, compared with plot 5, the two grasses mentioned are in much less proportion, and others are becoming characteristic of the plot. The *Agrostis* especially has gone down very much; *Holcus* has very much increased; and *Dactylis glomerata*, *Avena elatior* and *pubescens*, *Lolium perenne*, and *Poa pratensis*, are more favoured than on plot 5. Not only did the gramineous herbage become more mixed under the influence of the substitution of the mineral for the nitrogenous manure, but the character of development was totally different. In the first season the grasses showed a healthy, rather light-green, instead of the dark bluish-green, colour. The patchy character has gradually disappeared, and there is not only a free bottom growth, but there is more and more tendency to form stem and seed.

The Leguminosæ, which together had never contributed half a per cent. to the produce under the influence of the ammonia-salts alone, now began to increase in prominence; and, in 1877, they contributed nearly 7 per cent. to the hay. Neither *Trifolium pratense*, nor *Trifolium repens*, has, however, recovered any prominence in the produce. Nor has the deep-rooting *Lotus corniculatus* increased; but the creeping and comparatively surface-rooting *Lathyrus pratensis*, which is by far the most prominent leguminous plant on plot 7, where there has been a liberal top-dressing of mineral manure, including potass, from the commencement, appears to be rapidly gaining ground.

Of miscellaneous species, too, there has been, since the application of the mineral manure, a greater number fairly represented, and a greater proportion and actual amount by weight in the produce than where the ammonia-salts are still applied. The total number of species of all orders found on the plot has also considerably increased under the influence of the mixed mineral manure.

Thus, since the application of the mixed mineral manure, the flora of the plot has become much more complex. With this, 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 called the normal stores of the soil and subsoil, would be drawn upon. That such was really the case may be 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 manures alone had been applied for 20 years, and where the very complex and highly leguminous herbage accumulated, throughout the period, an otherwise unaccountably large amount of nitrogen.

With the differences—in the amount of produce, in the botany, in the character of development of the herbage, and in the probable sources of the nitrogen of the crop, the change in its chemical composition was also extremely marked.

Although there was very little less nitrogen taken up than where the ammonia-salts were still applied, the percentage of nitrogen in the dry substance of the mixed herbage was reduced by more than one-third. In other words, with the increased supply of mineral matter there was, for a given amount of nitrogen taken up, a greatly increased growth, involving a greatly increased amount of carbon assimilated.

Of total mineral matter there was, with the increased supply of it, an increased instead of a much reduced actual amount of it taken up; in fact, there was twice as much taken up during the seven years as where the application of ammonia-salts alone was continued, and the percentage of it in the dry matter of the produce was also higher. 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 potass there was nearly four times, of phosphoric acid about two-and-a-half times, of sulphuric acid about one-and-a-half time, and of silica (of which none was supplied in the manure) more than one-and-a-half time, 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 (on plot 7).

But, notwithstanding the greater actual amount of the mineral constituents taken up on plot 6 than on plot 5, there was, with the more healthy character of development and better maturation, an actually lower percentage of lime, magnesia, soda, and chlorine, in the dry substance of the produce. On the other hand, the percentage of potass in the dry substance was considerably more than twice as high, that of phosphoric acid one-and-a-half time as high, and that of silica rather higher, under the influence of the mineral supply, and with it better characters of growth. Still, the percentage of phosphoric acid, lime, and potass, especially of the two latter, was not so high as where the mineral manures had been supplied throughout the whole period (on plot 7); and where, accordingly, there was a still greater proportion of leguminous herbage, and the grasses developed more flower stems.

In conclusion, it is obvious that it was of potass 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 illustrated how ineffective was a supply of phosphoric acid (superphosphate of lime) when used alone, and how comparatively little was its effect when used in conjunction with ammonia-salts, but without potass; and we have here again strikingly brought out the influence of a liberal available supply of potass within the soil, both upon the quantity and the quality of the produce. Lastly, such evidence as is at command on the point does not favour the supposition that any considerable proportion of the nitrogen of the ammonia-salts applied during the 13 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 influences of the mixed mineral manure.

In connexion with these results showing the effects of a pretty complete mineral manure, used after the continuous application of an excess of ammonia-salts alone for a number of years, brief reference may be made to a somewhat parallel experiment.

When considering the results obtained on plot 15, manured for 18 years in succession with 550 lbs. per acre of nitrate of soda alone, containing 82 lbs. of nitrogen, or approximately the same amount as the 400 lbs. of ammonia-salts employed on plots 5 and 6, attention was called to the fact that the nitrate alone gave considerably more produce, containing more nitrogen, much more mineral matter, and falling off much less in the later years, than where the ammonia-salts were applied. The herbage, too, was both more mixed and better developed under the influence of the nitrate. It was pointed out that these better results were doubtless in great part due to the more rapid, wider, and deeper, distribution of the nitrogen of the nitrate, than that of the ammonia-salts. Plants of a more varied root-range were thus encouraged; possession of a greater range of soil was thus acquired; and probably the reactions within the soil and subsoil liberated more of their mineral constituents. But, as the 550 lbs. of nitrate had come, in the later years, to yield only about the same amount of produce as half the quantity used on another plot (17), and it was estimated that only a comparatively small proportion of the nitrogen applied was recovered in the increased crop, it was decided, as in the case of plot 6 with the ammonia-salts, to stop the further supply of the nitrate, and to apply the mixed mineral manure instead.

The change has thus far extended only over three years, 1876–77–78; but the field, the botanical, and the chemical, results already obtained are of marked character, and of much interest, and may fitly be referred to in general terms in this place.

Under the influence of the nitrate, not only was the herbage more complex than with the ammonia-salts, but the grasses were less patchy and tufty, not of so dark a green colour, and yielded more stem, much of which, however, bleached rather than ripened, apparently from mineral exhaustion. There was scarcely any leguminous herbage; but species of other orders contributed about one-fifth of the produce; *Rumex acetosa* was prominent, but decreased in the later years; but the most prominent, and increasing as the experiment proceeded, was the *Cerastium triviale, Achillea millefolium* coming next.

In the first year of the application of the mixed mineral manure instead of the nitrate, the plot assumed a lighter green colour, the grasses yielded more stem, matured better, and a greater number of them contributed to the bulk of the herbage. *Festuca ovina*, which had greatly increased, and contributed a very large proportion to the produce under the influence of the nitrate, still maintained the first place, but in much diminished quantity. *Holcus lanatus*, and *Agrostis vulgaris*, became much more prominent, and several other grasses gained ground. The leguminous plants, which had almost disappeared, immediately increased on the application of the mixed mineral manure, including potass; *Lathyrus pratensis*, as in other cases with the same manure, at once came forward. The number of miscellaneous species also increased; but the percentage by weight which they yielded to the produce was less, owing to the greatly increased and denser undergrowth of the grasses.

With the changes in the description of the herbage, and the character of its development, due to the change in the manure, there is, so far, a diminution in the average produce of the first crops; but as second crops were removed from the land in 1875 and 1877, the first crops of the three years 1876–77–78 would doubtless be affected by the consequent increased exhaustion. And, as a second crop was also taken in 1878, and will probably be so in future, the first crops may perhaps remain at a lower level. The average total produce, first and second crops together, is, however, considerably more over the last three years with the mineral manure, than that of the first crops only over the previous 18 with the nitrate.

In the total mineral matter, again, there is a somewhat less average amount removed in first crops, but a greatly increased amount taking first and second crops together. In first crops alone, however, there is twice as much potass, and nearly one-third more phosphoric acid, annually removed, since the change than previously, and very much more including the second crops. But, of lime, magnesia, chlorine, and silica, there is less removed in the first crops, and of soda only about one-seventh as much as previously. And, with the improved character of development of the herbage, the percentage of potass in its dry substance is more than twice, and that of phosphoric acid nearly one-and-a-half time, as high as previously.

Lastly, as to the nitrogen: its percentage in the dry substance of the produce (of first crops) has very much diminished, and the average amount of it removed per acre per annum is, in first crops, little more than half as much as, and even including second crops it is considerably less than, during the period of the application of the nitrate. Indeed, although the amount of produce under the influence of the mixed mineral manure succeeding the excess of nitrate is very much greater than without manure, there is, with the less mixed herbage than on the unmanured plot, and better development and maturation, especially of the grasses, a much lower percentage of nitrogen, and not much more total yield of it per acre, than without manure. Further, in the present season, 1879, the herbage of plot 15 has a very light colour, and upon the whole the appearance of restricted growth from deficiency of nitrogenous supply; much more so than is the case on plot 6, where the mixed mineral manures have for a longer period succeeded the ammonia-salts.

So far, therefore, there is little indication that much of the nitrogen previously supplied in the nitrate, and not recovered in the crops grown in the years of its application, will be gathered up under the influence of the mineral manure and the more varied flora it induces.

15. *Equal Nitrogen, and equal Potass, in Nitrate of Soda and Sulphate of Potass, and in Nitrate of Potass; in each case with Superphosphate of Lime; Plots* 19 *and* 20.

The marked effects of nitrate of soda, and of sulphate of potass, pointed to the interest of determining whether nitrate of potass, or a mixture of nitrate of soda and sulphate of potass, containing the same amounts of nitrogen and of potass, would be the most effective? Accordingly, in 1872, two plots (19 and 20) were set apart for experiments on the point. In each of the seven years, 1872–78 (and the experiment is still in progress), plot 19 has received 275 lbs. nitrate of soda, and plot 20, 327 lbs. nitrate of potass, both containing the same amount of nitrogen. Plot 19 has also received 290 lbs. sulphate of potass, containing the same amount of potass as the 327 lbs. nitrate of potass. Each plot has also received annually 3½ cwts. superphosphate of lime. For comparison with the results so obtained there is also given, in the following table, the average produce over the same seven years, and also over the preceding 14 years, on plot 16, manured annually, during the whole period of 21 years, with 275 lbs. nitrate of soda, 300 lbs. sulphate of potass, 100 lbs. sulphate of soda, 100 lbs. sulphate of magnesia, and 3½ cwts. superphosphate of lime.

TABLE XVIII.—Average, per acre per annum, by Nitrate of Soda and Sulphate of Potass, and by Nitrate of Potass, containing equal Nitrogen and equal Potass, in each case with Superphosphate; Plots 19 and 20.

		Per acre per annum.		
		Plot 16. 275 lbs. nitrate soda, 300 lbs. sulphate potass, 100 lbs. sulphate soda, 100 lbs. sulphate magnesia, 3½ cwts. superphosphate.	Plot 19. 275 lbs. nitrate soda, 290 lbs. sulphate potass, 3½ cwts. superphosphate.	Plot 20. 327 lbs. nitrate potass, 3½ cwts. superphosphate.
Hay.				
		lbs.	lbs.	lbs.
14 years, 1858–1871.	One crop only each year	5451	..	..
7 years, 1872–1878.	First crop only each year	4716	4368	4362
	Including second crops, 1875–77–78	5639	5273	5191
Nitrogen.				
14 years, 1858–1871.	One crop only each year	66·1	..	..
7 years, 1872–1878.	First crop only each year	54·0	49·1	47·9
	Including second crops, 1875–77–78	69·0	62·5	61·1
Mineral Matter (Ash).				
14 years, 1858–1871.	One crop only each year	331·4	..	..
7 years, 1872–1878.	First crop only each year	283·8	261·4	254·4
	Including second crops, 1875–77–78	369·9	336·4	322·6

It will be seen that the three plots received the same amount of nitrogen as nitric acid. Plots 19 and 20 received the same amount of potass, and plot 16 about 5 lbs. per acre per annum more. All three received the same amount of superphosphate of lime. But plot 16 received annually 100 lbs. sulphate of soda, and 100 lbs. sulphate of magnesia, in addition. Thus, plot 16 received rather more potass, and more soda, magnesia, and sulphuric acid, than plot 19; and plot 20, with the same amount of nitrogen and potass as 19, received no soda, and less sulphuric acid, but the nitric acid and the potass were applied to the soil in combination.

It is to be borne in mind that, in each of the 14 seasons (1858–1871), only one crop was removed each year; the after-growth being either fed off by sheep having no other food, or mown, spread on the land, and left to decay; but, in 1875, 1877, and 1878, a second crop was removed from these and all the other plots. The table therefore gives the average annual produce of one crop only each year, over the 14 years on plot 16, but over the seven years (1872–1878), for each plot, both excluding and including any second cuttings. It is seen that plot 16, which annually received the same amount of nitric acid, but a fuller mineral manure, and was under experiment 14 years before plots 19 and 20, yielded over those 14 years more produce of hay, containing more nitrogen, and more mineral matter, than the first crops of the succeeding seven years, but less than when both the first and second crops of the later period are taken together. Again, whichever basis of comparison be taken, plot 16 yielded, over the seven years, more hay, containing more of both nitrogen and mineral matter, than either plot 19 or 20. Plot 19 again, with the nitrate of soda and sulphate of potass, which, besides the difference of condition, supplied soda, and more sulphuric acid, yielded rather more in each particular, especially of mineral matter, than plot 20 with the nitrate of potass.

As on plot 16, so on plots 19 and 20, a fairly mixed herbage has been maintained. With only a moderate supply of nitrogen, and this in the form of nitrate, and with a liberal supply of potass, leguminous herbage increased on all three. The increase was, in each case, mainly due to the greatly increased growth of *Lathyrus pratensis;* but on plots 19 and 20 to some increase in *Trifolium repens* also. The percentage of miscellaneous species has gone down considerably since the commencement, on plot 16; but, as yet, it has not done so on plots 19 and 20; and with the greatly increased amount of total produce since the application of the manures, there is an increase in the actual amount of such herbage grown per acre. 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 than on either of the other plots; *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 both plots, 19 and 20, *Festuca ovina* is more prominent, as also, and increasing, is *Holcus lanatus.* On both, *Agrostis vulgaris,* though much decreasing, is still in considerable quantity; whilst *Alopecurus pratensis, Avena flavescens* and *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.

Although there is a notably smaller yield per acre of dry matter, of nitrogen, and of mineral matter, on plots 19 and 20 than on plot 16, the percentages in the dry substance, of both nitrogen and mineral matter, are very similar in the produce of plots 19 and 16, but in that of plot 20 they are rather lower, whilst the percentage of the dry substance itself in the air-dried hay was rather higher. These conditions would, with the comparatively similar botanical composition of the produce, indicate greater maturation, or ripeness, on plot 20 with the nitrate of potass, than on plot 19 with the nitrate of soda and sulphate of potass.

The analyses of the ash of the produce of the first crops for the seven years, and of the second crops for the three years, show that that of plot 16, with the fuller mineral manure and the longer continuance of the experiment, contained, both per acre and per cent. in its dry substance, more phosphoric acid, considerably more potass, and rather more magnesia, than that of either plots 19 or 20. On the other hand it contained, both per acre and per cent., less lime than that of either of the other plots, and at the same time less soda and chlorine than that of plot 19; but that of plot 20, with nitrate of potass, but without soda in the manure, contained very much less soda than that of either plot 16 or 19 with it. The produce of plot 20 again, contained less of sulphuric acid, chlorine, and silica, than that of plot 19; but more of lime, and especially more of potass, both per acre and per cent. These differences are, so far as they go, also consistent with a more advanced condition of maturity of the produce of plot 20.

There is, then, so far, no marked difference in the amount, or in the botanical composition, of the produce, whether the nitrogen and the potass be supplied as nitrate of soda and sulphate of potass, or as nitrate of potass; 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 potass.

16. *Mixture, supplying the Ash-constituents, and the Nitrogen, of* 1 *ton of Hay; Plot* 18.

We have the results of one more experiment with artificial or chemical manuring substances to give in this section—those obtained on plot 18. Commencing in 1865, there has been applied annually to this plot, a mixture containing the quantities of potass, soda, lime, magnesia, phosphoric acid, silica, and nitrogen, contained in 1 ton of hay. The mixture also supplied sulphuric acid and chlorine in abundance. The object of the experiment was, in part, to put to the test of direct experiment the principles of manuring put forward by LIEBIG, according to which all the constituents, neither more nor less, which we remove in crops, should be returned to the soil. He says:—

"By an exact estimation of the quantity of ashes in cultivated plants, growing on various kinds of soils, and by their analysis, we will learn those constituents of the plants which are variable, and those which remain constant. Thus also we will attain a knowledge of the quantities of all the constituents removed from the soil by different crops.

"The farmer will thus be enabled, like a systematic manufacturer, to have a book attached to each field, in which he will note the amount of the various ingredients removed from the land in the form of crops, and therefore how much he must restore to bring it to its original state of fertility. He will also be able to express in pounds' weight, how much of one or of another ingredient of soils he must add to his own land, in order to increase its fertility for certain kinds of plants." ("Agricultural Chemistry," 4th ed., pp. 212–213.)

He further says as to the object of manuring:—

"This purpose is the restoration, or an increase of the original fertility, and by manure we must replace all the constituents of the plants which have been taken away in the harvest, or which are contained in the plants which we are desirous to cultivate." (Address—"On the Principles of Artificial Manuring," p. 26.)

Again, in ridicule of the different plan followed in our experiments, he says: "Shall we do as Mr. LAWES did . . . . ?" and in answer he adds: "Truly, in such cases, there is no other guide but logic, that is, sound common sense, which tells us, *to give to the land what we have removed from it, neither more nor less.* Of course, this is on the assumption that the land is *to retain its original fertility* only, not to be rendered more fertile than before." ("Principles of Agricultural Chemistry," p. 63.)

And again: "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.*" (*Ib.*, pp. 83–84.)

Another of the objects of the experiment was to acquire data as to the proportion in which the several constituents artificially supplied would be recovered in the increase of crop—a question the fuller consideration of which must be postponed to the third or Chemical Section of our report.

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

76 lbs. commercial chloride potassium . .	38 lbs. potass. 7 lbs. soda. 36·7 lbs. chlorine.
35 lbs. sulphate magnesia	5·6 lbs. magnesia. 11·1 lbs. sulphuric acid.
26 lbs. bone-ash	11·0 lbs. lime. 8·2 lbs. phosphoric acid.
26 lbs. sulphuric acid (sp. gr. 1·7) . . .	16·9 lbs. sulphuric acid.
50 lbs. silicate soda	? lbs. soda. 23·0 lbs. soluble silica.
50 lbs. silicate of lime	? lbs. lime. 8·0 lbs. soluble silica.
164 lbs. "ammonia-salts"	34·0 lbs. nitrogen. 44·4 lbs. sulphuric acid. 46·2 lbs. chlorine.

If the quantity of constituents supplied, as shown in the right-hand column of the above tabular statement, be compared with the figures given on page 298 for the contents of $1\frac{1}{2}$ ton of hay, it will be seen that fully sufficient of all the constituents have been supplied for an increase of 1 ton of hay, whilst of soda, sulphuric acid, and chlorine, much more than sufficient has been applied.

The experiment had been conducted 11 years, from 1865 to 1875 inclusive; and the following table gives the average produce per acre per annum over the first five-and-a-half, the second five-and-a-half, and the total period of 11 years; that is, the produce of the first five years, together with half that of the sixth, is divided by 5·5; and, again, the produce of the last five years and half of the sixth is, in like manner, divided by 5·5. For comparison, the average produce obtained on the unmanured plot 3 is also given for the same periods.

TABLE XIX.—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 18. Nitrogen and ash-constituents of 1 ton of hay.	Plot 3. Without manure.	Plot 18. + or − unmanured.
HAY.			
	lbs.	lbs.	lbs.
First period, $5\frac{1}{2}$ years	3908	2514	+1394
Second period, $5\frac{1}{2}$ years	3301	1787	+1514
Total period, 11 years, 1865–75	3604	2151	+1453
Second period, per cent. + or − first period	−15·5	−28·9	
NITROGEN.			
First period, $5\frac{1}{2}$ years	50·1	35·1	+15·0
Second period, $5\frac{1}{2}$ years	39·9	24·3	+15·6
Total period, 11 years, 1865–1875	45·0	29·7	+15·3
Second period, per cent. + or − first period	−20·4	−30·8	
MINERAL MATTER (ASH).			
First period, $5\frac{1}{2}$ years	222·7	146·7	+76·0
Second period, $5\frac{1}{2}$ years	175·7	96·9	+78·8
Total period, 11 years, 1865–1875	199·2	121·8	+77·4
Second period, per cent. + or − first period	−21·1	−33·9	

The average yield obtained on the application of the mineral constituents and the nitrogen contained in 1 ton of hay was, over the first half of the period, about 35 cwts., over the second half rather less than 30 cwts., and over the whole period rather more than 32 cwts. of hay. There was, therefore, a reduction in the total produce in the later years.

But, obviously, before we can estimate the effects of the manure, we must 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 experiments in 1856, and for some years previously, we shall arrive at an approximate estimate of the amount of produce due to the manure, if we deduct from the total amount that obtained on the unmanured plot over the same seasons. Reckoned in this way, we have an average annual increase of produce, due to the manure, of not quite $12\frac{1}{2}$ cwts. during the first period, about $13\frac{1}{2}$ cwts. during the second, and not quite 13 cwts. over the whole 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.

Whilst it is clear from the above comparisons, 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, it is at the same time pretty certain that the differences in the amounts of hay, nitrogen, and mineral matter, obtained, without and with the manure, do not accurately represent the proportion of the constituents supplied which contributed to the result; for, one effect of the manure was very materially to modify the character of the herbage. The percentage in the produce, and the amount per acre, of gramineous herbage, were much increased; both the percentage, and the actual amounts, of leguminous herbage were much reduced; the percentage of the miscellaneous herbage was also reduced, though the amount of it per acre was increased. Thus, whilst the amount of leguminous herbage, which is to a great extent independent of direct supplies of nitrogen by manure, was reduced, the increase of produce consisted almost exclusively of gramineous herbage, the increased growth of which would doubtless depend—mainly, at any rate—for the nitrogen it required, on that which was artifically supplied; and, therefore, probably a larger amount of that supplied contributed to the increase than the table shows.

As in the case of the nitrogen, so also in that of each of the mineral constituents, there was always very much less, and sometimes more than one-half less, increased amount in the produce removed, than was supplied in the manure; and in the case of some important constituents—potass, for example—a less proportion of that supplied was recovered as increase than when larger amounts of both the mineral and the nitrogenous manures were applied, and when, consequently, greater luxuriance of the grasses was induced. And, notwithstanding potass is very little subject to loss by drainage, and there would therefore be an annually increasing residue of it within the soil, there is even less of it taken up during the second than during the first half of the period of experiment. There is, nevertheless, a higher, but a decreasingly higher, percentage of potass in the manured, than in the unmanured produce. There is also a higher percentage of soda, of phosphoric acid, of sulphuric acid, and of chlorine, but a lower percentage of lime, magnesia, and silica.

These results suggest several points of interest.

It has already been shown, in experiments in which comparatively large quantities of ammonia-salts or nitrate of soda were used, how much greater was the increase of produce, how much more mixed was the herbage, and how much better it was developed, when a given amount of nitrogen was applied as nitrate of soda than when as ammonia-salts; the difference in favour of the nitrate in these respects being much the greater when these nitrogenous manures were respectively used alone—that is, without the conjunction of mineral manures. On plot 18—with nearly one-fifth less nitrogen annually applied as ammonia-salts than on either plots 16, 19, and 20 as nitrate of soda, and therefore with less forced luxuriance, but, it is true, at the same time, with less (though still an excess) of mineral constituents supplied—the description and condition of the herbage (on plot 18) were inferior; a somewhat larger proportion of the produce was made up of a few of the poorer grasses; leguminous herbage was greatly reduced; and among miscellaneous species *Rumex acetosa* was more prominent.

Again, the results afford a pretty direct test of the validity of the principle according to which all, and neither more nor less, of the constituents removed from the land in crops, should be returned to it in manure.

In LIEBIG'S earlier writings he 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 the principle under the actual conditions of practical agriculture, attention may be called to the following considerations:—

In the first place, 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.

In the second place, the principle ignores the difference in the character and capabilities of different soils. Take, by way of illustration, two extremely 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 potass, 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 the 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 of food-collection. The barley, on the other hand, depends very much more upon the stores available within the surface soil. Again, superphosphate of lime 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.

Having now considered the effects of various important individual constituents of manures, and of various combinations of them, on the mixed herbage of permanent meadow land, we are in a position the better to interpret the results obtained on the application of that complex and heterogeneous mixture—farmyard manure.

For eight years—1856–1863 inclusive—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 200 lbs. ammonia-salts per acre per annum in addition. At the end of the eight years, the application of the farmyard manure was stopped on both plots; but the ammonia-salts were still annually applied to plot 1. The cessation of the application of the farmyard manure was decided upon—partly because so large a quantity annually applied 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.

The following table shows the average produce of hay, and its contents of nitrogen and mineral matter, over the eight years of the application of the dung, over the first six, and the second six, succeeding years, and over the total period of 20 years, on both plots 2 and 1. For comparison, there is also given the average produce on the unmanured plot 3, over the same periods; and lastly, the increase on plots 2 and 1 respectively, over the produce without manure, and the increase on plot 1 with, over the yield on plot 2 without, the ammonia-salts.

TABLE XX.—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 continuously.	Plot 2. Farmyard manure alone 8 years, 1856-1863; unmanured 12 years, 1864-1875.	Plot 1. Farmyard manure and ammonia-salts 8 years, 1856-1863; ammonia-salts only 12 years, 1864-1875.	Plot 2. + or − unmanured.	Plot 1. + or − unmanured.	Plot 1. + or − plot 2.
HAY.						
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
First period, 8 years, 1856-1863	2665	4804	5538	+2139	+2873	+734
Second period, 6 years, 1864-1869	2699	4846	5366	+2147	+2667	+520
Third period, 6 years, 1870-1875	1692	2517	3331	+ 825	+1639	+814
Total period, 20 years, 1856-1875	2383	4130	4824	+1747	+2441	+694
Second period, per cent. + or − first period	+ 1·3	+ 0·9	− 3·1			
Third period, per cent. + or − first period .	−36·5	−47·6	−39·9			
NITROGEN.						
First period, 8 years, 1856-1863	37·2	58·2	68·3	+21·0	+31·1	+10·1
Second period, 6 years, 1864-1869	37·3	53·3	63·9	+16·0	+26·6	+10·6
Third period, 6 years, 1870-1875	23·0	27·5	41·0	+ 4·5	+18·0	+13·5
Total period, 20 years, 1856-1875	33·0	47·5	58·8	+14·5	+25·8	+11·3
Second period, per cent. + or − first period	+ 0·3	− 8·4	− 6·4			
Third period, per cent. + or − first period .	−38·2	−52·7	−40·0			
MINERAL MATTER (ASH).						
First period, 8 years, 1856-1863	160·5	329·1	370·5	+168·6	+210·0	+41·4
Second period, 6 years, 1864-1869	152·2	275·0	291·8	+122·8	+139·6	+16·8
Third period, 6 years, 1870-1875	91·5	136·4	164·7	+ 44·9	+ 73·2	+28·3
Total period, 20 years, 1856-1875	137·3	255·0	285·1	+117·7	+147·8	+30·1
Second period, per cent. + or − first period	− 5·2	−16·4	−21·2			
Third period, per cent. + or − first period .	−43·0	−58·6	−55·5			

It will be convenient first to consider the effects of the farmyard manure used alone, over the eight years of its application, and those of its residue afterwards; and then the difference of effect produced by the use of 200 lbs. of ammonia-salts per acre per annum, both during the eight years of the application of the farmyard manure, and during the subsequent 12 years of the action of the residue.

Over the eight years of the application of the farmyard manure, there was an average produce of 4804 lbs. of hay, equal to an average annual increase over that without manure of 2139 lbs. It is remarkable that, over the first six years after the cessation of the application of the manure, the average produce was almost exactly the same as, and even rather more than, during the eight years of the application, namely, 4846 lbs; and the average annual increase was also almost identical, being 2147 lbs. This result was, indeed, partly due to one or two of the six years being seasons of very high productiveness; but still it is very striking. During the next six years there was one season of unusual drought, and others of much less than average productiveness; and, under these circumstances, together with the fact that the then remaining residue would doubtless be in a less readily available condition, there was 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. Still, there was an increase of between 6 and 7 cwts. of hay, due to the residue, in 1875, the twelfth year after the cessation of the application of the manure, and of more in 1876 and 1877.

The table further shows 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. But the amount was not, as was that of the hay, as much per acre per annum over the first six years as it had been over the eight of the application; and over the second six years there was little more than half as much as over the first six, and the average annual increase was only about 4½ lbs., against 16 lbs. over the first six years.

Of mineral matter, again, 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 developed, to bring into greater prominence the gramineous and the miscellaneous herbage, but to reduce the leguminous. The gramineous herbage became less mixed, a few individual species contributing a larger proportion of the hay. Of these, *Poa trivialis*, *Bromus mollis*, and *Avena flavescens*, were the most prominent; whilst, without manure, neither of these was in any marked quantity, but *Festuca ovina*, *Agrostis vulgaris*, *Avena pubescens*, and *Holcus lanatus* were the leading grasses, and *Lolium perenne*, *Anthoxanthum odoratum*, and some others, were fairly represented. After the cessation of the application of farmyard manure, however, the same grasses as without manure gradually became the more prominent on plot 2, whilst the *Poa trivialis* and *Bromus mollis* were, in 1877, represented in very insignificant amounts. Upon the whole, indeed, the general character of the herbage on the unmanured, and the farmyard-manure plot, especially in the later years, has not been very strikingly different; and the difference may, for our present purpose, be summed up in the statement that there was, on the manured plot, 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 lastly, a rather lower percentage, but a somewhat larger actual amount, of miscellaneous herbage.

With the greater proportion of gramineous and less of leguminous herbage in the produce by the farmyard-manure, there was a considerably lower, and a decreasing, percentage of nitrogen in it; but there was a higher percentage of total mineral matter. Of lime, magnesia, soda, and sulphuric acid, there was more, and of potass, phosphoric acid, chlorine, and silica, very much more, removed per acre from the farmyard-manured than from the continuously unmanured plot. The percentages of lime, magnesia, soda, and sulphuric acid, were, however, all lower in the dry substance of the produce by the farmyard manure; but those of potass, phosphoric acid, chlorine, and silica, were not only in very much larger actual amount, but in higher percentage in the produce of the manured plot; and (excepting chlorine) this was so even in the later years. It is clear, therefore, that there was a greater or less available residue of all the mineral constituents, and more especially of potass, phosphoric acid, and silica, many years after the cessation of the application of the manure.

It is obviously a matter of very great interest to consider at what rate, and in what proportion, the several constituents of the farmyard manure which were not recovered during the years of the application, have been so since, and what prospect there is of their final total recovery? These are questions which will be considered more in detail in the chemical section of our report, but a few general observations on the subject seem to be called for in this place, to enable us to form any just conception of the character of the agricultural results.

We have sufficient analytical data on which to found a pretty correct estimate of the amounts of nitrogen, and of the several mineral constituents, removed in the crops during the separate periods; but we have not any such sure basis for the estimation of the amount of the same constituents contained in the 112 tons of farmyard manure applied per acre to the plot during the eight years. We are obliged, therefore, to adopt the best estimate we can of the constituents supplied in the manure, founded on much data, both synthetic and analytic, relating to the subject, and a careful consideration of them. The result must obviously be only approximative, but it is doubtless sufficiently so to give considerable value and importance to its general indications.

Of nitrogen, it is estimated that the farmyard manure will, on the average, contain 0·64 per cent., and therefore that 200·7 lbs. were applied per acre per annum; or, in all, 1606 lbs. in the eight years. The total produce removed, during the eight years of the application, 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 20 years about 10 per cent. more, were removed, making in all about 59 per cent.

as much removed in the total produce of the 20 years, as had been supplied during the eight years. But obviously we must not assume that the whole of the nitrogen of the crops was derived from the manure. It would be nearer the truth to deduct the amount obtained in the unmanured produce, and to suppose only the so reckoned increase to be due to the manure. But, inasmuch as the manured produce contained considerably more gramineous herbage, which would probably depend largely on the artificial supply of nitrogen, and, further, as it contained upon the whole less total leguminous herbage, which would depend more on natural sources, it is probable that the manured produce might derive less nitrogen from such sources than the unmanured, especially in the presence of the presumably more readily available supply by the manure. Still, it is doubtless a nearer approximation to the truth to assume that only so much of the nitrogen of the manured produce as was in excess of that of the unmanured was derived from the nitrogen of the manure. Reckoned in this way, only 10·4 per cent. of the estimated 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 20 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 20 years, about 41 per cent. of the 1606 lbs., or about 658 lbs., 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 20 years, 81·9 per cent. of the nitrogen supplied—that is, about 1315 lbs.; and yet, during the last six years of the 20 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.

The question arises—whether this large amount of unrecovered supplied nitrogen does remain in the soil, and in such a condition of combination, and distribution, as to be available to succeeding crops? or whether some of it be not lost by drainage, or in other ways, and the remainder so locked up, or distributed, as to be so slowly recoverable, if ever, that it can be reckoned of scarcely appreciable practical value?

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 for 20 years, and before the next growing season had commenced. Table XXI. shows, for the unmanured plot (3), and for the plot (2) manured for eight years with farmyard manure, and then unmanured for 12 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 nine inches down to a depth of 54 inches;

(2) The percentage of nitrogen in the dry mould of each nine-inch 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 recorded amounts of dry soil per acre at each depth are the averages calculated from direct experimental data relating to the point, obtained in the case of three samples taken at each depth, from each of 22 plots. The determinations, and the estimates of the nitrogen per acre, in the respective soils, do not include the amount in roots separated from the soil-samples. Whilst, however, from the first nine inches of the unmanured soil 0·32 per cent. of roots was separated, in the corresponding layer of the farmyard-manured soil only 0·24 per cent. was found. There would, therefore, be no further accumulation in the manured soil due to this source. In the lower depths, again, the amounts of separated roots were very inconsiderable.

TABLE XXI.—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 continuously.	Plot 2. Farmyard manure 8 years; unmanured 12 years.	Plot 3. Unmanured continuously.	Plot 2. Farmyard manure 8 years; unmanured 12 years.	Plot 2. + or − plot 3.
	lbs.	Per cent.	Per cent.	lbs.	lbs.	lbs.
First depth, 1–9 inches . .	2,183,375	0·2565	0·2800	5600	6113	+513
Second depth, 10–18 inches .	2,835,339	0·0724	0·0849	2053	2407	+354
Third depth, 19–27 inches .	2,964,176	0·0458	0·0473	1358	1402	+ 44
Fourth depth, 28–36 inches .	3,049,436	0·0425	0·0402	1296	1226	− 70
Fifth depth, 37–45 inches. .	3,104,583	0·0381	0·0337	1183	1046	−137
Sixth depth, 46–54 inches .	3,080,909	0·0376	0·0319	1158	983	−175
Total, 27 inches . . .	7,982,890			9011	9922	+911
Total, 54 inches . . .	17,217,818			12,648	13,177	+529

Adopting the foregoing results as to the accumulation of the nitrogen of the manure within the soil on the basis of the determinations to the total depth of 54 inches, the next table shows—the estimated amounts supplied in the farmyard manure, recovered in the increase of crop, and not so recovered; the residue found in the soil to the depth in question; and the amount not so recovered, either in the increase or in the soil.

TABLE XXII.—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.
	lbs.	
Supplied in farmyard manure in eight 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 54 inches deep	529	32·9
Not recovered in increase or in soil	786	49·0

In interpreting these figures we have 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 the nitrogen in, the soils, and the calculation of such data into quantities per acre. Indeed, it appears at first sight anomalous, that the manured soil should show actually less nitrogen in the fourth, fifth, and sixth depths, than the unmanured; and, although the result may be due to differences in the subsoils themselves, irrespectively of the difference of recent treatment, it is at the same time not inconceivable that, with the accumulation of manurial matter in the upper layers of the manured soil, and the consequent increased luxuriance of the vegetation, more moisture, and with it more soluble nitrogenous compounds, might be drawn upwards from the lower layers than without manure, and in that case the mode of estimate adopted above would, so far, be the most correct. But if we take 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 results as to accumulation and loss of nitrogen will stand as follows :—

TABLE XXIII.—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.
	lbs.	
Supplied in farmyard manure in eight 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 27 inches deep	911	56·7
Not recovered in increase or in soil	404	25·2

But even allowing due weight to the difficulties and uncertainties above referred to, and whichever basis of calculation be adopted, there can be little 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. This is not wanting. Thus, among the series of field experiments at Rothamsted, wheat has been grown year after year on the same land from 1843–44 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 following Table (XXIV.) shows, for 20 years, the average annual amounts of nitrogen—estimated to be supplied in the farmyard manure, obtained in the produce by the mineral manure without nitrogen, in the produce by the farmyard manure, in the increase by the farmyard over the mineral manure, and the percentage recovered, and not recovered, in the increase.

TABLE XXIV.—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.
	lbs.	lbs.	lbs.	lbs.	Per cent.	Per cent.
Wheat, 20 years, 1852–71	200·7	20·1	49·3	29·2	14·6	85·4
Barley, 20 years, 1852–71	200·7	23·9	45·3	21·4	10·7	89·3

In comparing these results with one another, and with those obtained on the mixed herbage of permanent meadow land, it must be borne in mind that, in the case of the wheat, the farmyard manure had been applied, and the crop grown, for eight years preceding the period for which the calculations are made, and there was doubtless, therefore, already a considerable accumulated residue within the soil; and that, for both the wheat and the barley, the manure was applied in each of the 20 years, instead of only for eight years as for the grass. Further, in the case of the wheat and the barley the increase is reckoned over the produce by purely mineral manure, whereas in that of the grass it is taken over that without manure, since the effect of the mineral manure on the mixed herbage is to develop so much more of the highly nitrogenous leguminous plants.

The general result is that, according to the estimates, a higher proportion of the supplied nitrogen was annually recovered over the 20 years in the autumn-manured and autumn-sown (and longer so 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. But it will be obvious that 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. The comparison of the results with the cereal crops may indeed be taken to indicate that the proportion of the nitrogen of the farmyard-manured hay crops estimated to be derived from the manure is too low; and it would seem to be a further reason for this supposition, that, with the much greater variety of root-distribution, and of root-capacity, and a much longer season of greater or less activity of growth, in the case of the mixed herbage, there would also be a greater power of gathering up the supplies by manure. However this may be, the evidence as it stands points to the conclusion that, 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 the application.

In the case of the barley experiments, after the farmyard manure had been applied for 20 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 following table shows the result as to the recovery of the nitrogen of the manure in the two cases. In the upper division, are given the particulars for the 20 years (as already quoted), for the next six years, and for the 26 years, where the application was continued; and in the lower division, for the 20 years of the application, for the six years after the discontinuance, and for the 26 years, 20 with, and six without, the manure.

Table XXV.—Nitrogen supplied in Farmyard Manure, recovered, and not recovered, in increased produce of Barley, during the years, and after the cessation, of the application.

	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.
Farmyard Manure every Year; 26 Years.						
	lbs.	lbs.	lbs.	lbs.	Per cent.	Per cent.
20 years, 1852–1871	200·7	23·9	45·3	21·4	10·7	89·3
6 years, 1872–1877	200 7	15·5	47·1	31·6	15·7	84·3
Total period, 26 years . .	200·7	22·0	45·7	23·7	11·8	88·2
Farmyard Manure, 20 Years; Without Manure, 6 Years.						
20 years, 1852–1871	200·7	23·9	45·3	21·4	10 7	89·3
6 years, 1872–1877	..	15·5	35·3	19·8	2·9	..
Total period, 26 years . .	..	22·0	43·0	21·0	13·6	86 4

Thus, over the 20 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 crop; over the next six years of the continued application, on half the plot, 15·7 per cent., and over the total period of 26 years 11·8 per cent. On the other half, there was the 10·7 per cent. of the 20 years' supply recovered during the 20 years, 2·9 per cent. more of it during the next six years, and, in all, 13·6 per cent. of the 20 years' supply recovered in the 26 years. That is to say, of the 4014 lbs. of nitrogen estimated to be supplied in the 20 years, 86·4 per cent., or 3468 lbs., remained unaccounted for in the increase of crop at the end of the 26 years.

In reference to these results and conclusions, it is to be observed that the great reduction in the yield of nitrogen by the mineral manure in the later years is an indication of a gradual reduction of the more readily available nitrogen within the soil, and it is hardly to be supposed that, with the large supplies in the farmyard manure, the less readily available stores of the soil itself would be drawn upon to so great an extent as under the influence of the purely mineral manure. It is obvious that, so far as this was so, too much of the yield of nitrogen on the farmyard manure plot has been reckoned as derived from the soil, and too little as increase due to the manure—at any rate in the earlier years of the comparison; and this observation would apply to the estimates relating to wheat as well as to barley.

We have not taken samples of the soils of the barley plots, and have not therefore the means of estimating how much of the unrecovered nitrogen of the manure still remains in the soil, possibly to be gradually yielded up to succeeding crops. But, supposing 89·3 per cent. remained unaccounted for at the end of the 20 years of the application, and only 2·9 per cent. of the original supply were recovered in the first six years after the cessation of the application, or say 0·5 per cent. per annum, it would obviously take from 170 to 180 years to recover the whole of it, 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.

But samples of the soils of the experimental wheat plots have been taken, and the nitrogen determinable in them by the soda-lime method estimated, at various times. The results so obtained enable us to form some judgment as to whether or not the whole of the nitrogen of the farmyard manure which is not recovered in the increase of crop remains available within the soil.

In the autumn of 1865, after wheat had been grown 22 years in succession, samples of the soils were taken from many of the plots, in each case from the first nine, the second nine, and the third nine inches, of depth, or to a total depth of 27 inches. The results showed rather more than one-and-two-thirds as much nitrogen so determinable in the first nine inches of the farmyard-manured, as in the corresponding layer of the unmanured plot, and about one-and-a-half time as much as, to a corresponding depth, of any of the plots receiving artificial nitrogenous manures. The second and third nine inches also showed rather higher percentages than those of the unmanured, or of most of the artificially-manured plots. More recent determinations—that is, after the farmyard manure had been applied some years longer—showed more than twice as much nitrogen in the first nine inches as without manure. The following table gives the results for the two wheat plots, in the same form as at page 372 for the grass plots, founded on the determinations made on the samples of soil taken in 1865, after 22 years' application of farmyard manure, and 22 wheat crops had been removed. The estimates of dry soil per acre are, for each depth, the average results obtained relating to eight samples from each of 11 plots.

TABLE XXVI.—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-manured.	Plot 3. Unmanured.	Plot 2. Farmyard-manured.	Manured + or − Unmanured.
	lbs.	Per cent.	Per cent.	lbs.	lbs.	lbs.
First depth, 1-9 inches	2,287,155	·1090	·1882	2493	4304	+1811
Second depth, 10-18 inches	2,712,508	·0738	·0810	2002	2197	+ 195
Third depth, 19-27 inches	2,848,973	·0561	·0619	1598	1764	+ 166
Total, 27 inches	7,848,636			6093	8265	+2172

The next table shows the estimates of the nitrogen—supplied in the manure, recovered in the increase of crop, determined in the soil, and not recovered in either the increase or the soil.

TABLE XXVII.—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.
	lbs.	
Supplied in farmyard manure in 22 years	4415	
Recovered as increase of crops	470	10·7
Not recovered in increase	3945	89·3
Residue determined by soda-lime in soil 27 inches deep	2172	49·2
Not recovered in increase or in soil	1773	40·1

Here we have, over the first 22 years of the wheat experiments, only 10·7 per cent. of the supplied nitrogen estimated to be recovered as increased yield, against 14·6 per cent. over the last 20, of the first 28 years (*see* p. 374). There is about one-and-a-half time as large a proportion determined as residue in the wheat soil, and therefore a less proportion estimated as loss, than in the case of the hay-plot reckoned to the depth of 54 inches. On the other hand, if the latter be taken to only the same depth as the wheat plots—that is, to 27 inches instead of 54—the proportion of the supplied nitrogen estimated to remain as residue in the soil is greater, and that estimated as loss less, in the case of the permanent meadow than in that of the wheat plots. Thus, in the case of the wheat experiments, 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 27 inches of depth, 25·2 per cent., or to the depth of 54 inches 49 per cent.

It must be borne in mind that the whole of the estimates on this point, whether relating to wheat, to barley, or to grass, are based on the assumption that the 14 tons of farmyard manure annually applied contained 0·64 per cent., or 200·7 lbs., of nitrogen; and if it did not contain so much, the percentage recovered was of course greater, and that not recovered less, than the foregoing calculations indicate. But it is at any rate clear that only a comparatively small proportion of the nitrogen so supplied 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 nine inches of depth.

But, according to the estimates, besides the actually determined large, but comparatively ineffective, residue within the soil, there was also in each case a very large amount unaccounted for, either in the increase of crop or in the soil, to the depths examined. The quantity to be estimated as lost would, of course, be less if the estimate of the amount supplied be too high; again, by so much as may be retained as nitric acid, and not accounted for by the soda-lime method; and, again, by so much as may remain, either as nitric acid or in other forms, below the depth experimented on, but nevertheless not beyond the reach of root-collection, or of capillary action bringing up the stores from the lower to the upper layers.

Direct experiments have shown that the soil in the experimental 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. It is, accordingly, found that the drain from the farmyard-manured plot runs much less frequently than do those from the unmanured or the artificially manured plots. There will, obviously, be less loss of water by drainage. Direct experiments further show, however, that a given volume of the drainage water which does run from the farmyard-manured plot contains from two to three or more times as much nitrogen as nitrates and nitrites as that from the unmanured plot, or from the plots with mineral without artificial nitrogenous manure. We have here, therefore, a determined source of loss of the supplied nitrogen. But such calculations as the data admit of lead to the conclusion that the whole of the estimated loss cannot be accounted for in this way. The probability is that there is a considerable additional loss by decomposition of the nitrogenous organic matter within the soil, and evolution as free nitrogen.

There is, then, 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 of it by drainage; and, finally, that there is probably a further loss by decomposition, and evolution into the atmosphere.

However significant these illustrations may be, it must be borne in mind 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 proportionally less. Much, obviously, would also depend upon 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 it might indeed have been expected that, with the very varied herbage of grass-land, and possession of the soil by the roots of many descriptions of plant, the year round, a better result would have been obtained with the mixed herbage as compared with the cereal crops, than the evidence, as it stands, would 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.

So much for the nitrogen. It will be of interest also to consider whether or not the most important mineral constituents of the manure are as slowly available to the crop.

Of the amount of lime estimated to be supplied in the manure in the eight years, only about $12\frac{1}{2}$ 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 $25\frac{1}{2}$ per cent. in the 20 years. Deducting the yield in the unmanured produce, however, there was an increase obtained representing only $3\frac{1}{2}$ per cent. of the amount estimated to be supplied during the eight years, little more than 2 per cent. in the next six years, a small fraction of 1 per cent. in the second six, and not quite 6 per cent. in the 20 years.

Of the magnesia, a much larger proportion would appear to be taken up; that in the total produce (of the 20 years) amounting to nearly 70 per cent., and the estimated increased yield to about 21 per cent. of that supplied.

Of the potass estimated to be supplied in the eight years, the produce of the period contained 44 per cent. as much, that of the next six years $22\frac{1}{2}$ per cent. more, and that of the last six years $10\frac{1}{2}$ per cent. more; in all, 77 per cent. But the increased yield of potass represented only $30\frac{1}{2}$ per cent. during the eight years, scarcely 13 per cent. during the next six, and only $4\frac{1}{2}$ per cent. during the last six years; in all, only about 48 per cent. of that supplied. This result, however, upon whichever basis taken, shows a great effect from the potass of the dung, though a much diminishing one in the later years. It is known that potass 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.

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

Of phosphoric acid, a larger proportion of that supplied, though not so much as of the potass, would appear to be taken up. In the 20 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 potass, is very little subject to loss by drainage.

Of sulphuric acid, there is a much less increased amount found in the ash of the crop, in proportion to that estimated to be supplied, than of phosphoric acid.

Of chlorine, the increased amount found in the produce is, during the years of the application of the manure, greater in proportion to the estimated supply than that of any other constituent; but the proportion diminishes more rapidly in the subsequent years 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 20 years contained about $41\frac{1}{2}$ per cent. as much as there was estimated to be supplied of soluble silica in the dung, and the increased yield of it represented about 22 per cent.

Thus, of the three more important constituents of manure, nitrogen, potass, 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 applied; 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 potass, 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 potass; it too, like the potass, 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 elements in the scientific explanation of the practically recognised much lower money value of a given amount of nitrogen so supplied.

It remains to point out the difference of effect when, besides the farmyard manure, 200 lbs. of ammonia-salts were also annually applied per acre, both over the eight years of the application of the dung, and over the next 12 years of the action of the residue. As already explained, plot 1 was devoted to this experiment.

Under the influence of the addition of the ammonia-salts, the growing herbage acquired a darker green colour; gramineous species became more, and both leguminous and miscellaneous species less prominent, than either on the unmanured plot or that with the 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, the *Poa trivialis*, the *Bromus mollis*, and the *Dactylis glomerata*, went down very much. Other grasses were represented in less number, and generally in less proportion, on the plot with ammonia.

Of leguminous plants, *Lathyrus pratensis* is the most prominent on both plots; but, whilst without the ammonia the quantity at the last separation was between 5 and 6 per cent., with the ammonia there has been but a fraction of 1 per cent. of it; and, again, without ammonia there was nearly 1 per cent. of *Trifolium pratense*, but with it there was none at all.

Of miscellaneous species, many more were fairly prominent without than with the ammonia; though with it, *Rumex acetosa* was not only much more prominent than without it, but yielded a very large proportion of the total miscellaneous herbage. Finally in reference to the botanical character of the produce—a much greater number of species, gramineous, leguminous, and miscellaneous, contribute to the produce without, than to that with, the ammonia-salts.

In Table XX., p. 368, the produce of hay, and its contents of nitrogen and mineral matter, are given, for each period, with the farmyard manure and ammonia-salts, side by side with those on plot 2 with the farmyard manure alone.

Over the eight years of the application of the dung, there was an average of 734 lbs., over the first six years after the cessation, 520 lbs., over the next six years, 814 lbs., and over the whole period of 20 years, 694 lbs., more hay by the dung and ammonia-salts, than by the dung alone. Although the increase of produce, due to the ammonia-salts, was thus 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 200 lbs. of ammonia-salts annually applied are estimated to supply about 41 lbs. of nitrogen, equal to about 50 lbs. ammonia. The increased yield of nitrogen in the crop was, however, only 10·1 lbs. per acre per annum over the first eight years, 10·6 lbs. over the next six, 13·5 lbs. over the last six, and 11·3 lbs. over the 20 years. In other words, there was, so reckoned, an average of only about 27½ per cent. of the nitrogen so supplied recovered as increase in the crop.

Of mineral matter, there was also an increased amount taken up under the influence of the ammonia-salts. But, as without manure, and as with farmyard manure alone, the actual amount annually taken up was very much less over each succeeding period; indeed, on both plots, 2 and 1, it was considerably less than half as much over the last six years as over the eight years of the application of the dung. Still, the ammonia-salts undoubtedly had the effect of increasing the amount of mineral matter taken up.

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. Of sulphuric acid and chlorine there was, of course, a considerable quantity annually applied in the mixture of sulphate and muriate of ammonia used. Of potass, there was an increased amount taken up during the first eight years, actually rather less during the next six years, and very little more during the last six—in all, over the 20 years, not 3 lbs. per acre per annum more taken up with, than without, the ammonia-salts. There was, however, over each period, very much more soda taken up with the ammonia-salts, and over the whole period there was nearly three times as great an increase of soda as there was of potass in the produce. Of silica, there was rather more taken up with ammonia than without it over the eight years of the application of the dung, but rather less subsequently, and over the 20 years all but identical amounts on both plots.

It is obvious that the increased amounts of lime and magnesia, of potass and soda, and of phosphoric acid, taken up under the influence of the ammonia-salts, must have had their source in the previous supplies within the soil, or in the residue from the farmyard manure; and, so far, the action of the ammonia-salts has been more rapidly to utilize, and therefore the more to exhaust, these otherwise dormant stores. But, from the very slight increase in the amount of potass taken up, and the very much greater increase in that of soda, it may be concluded that there was a relative deficiency of available potass within the soil, notwithstanding the comparatively large amount probably supplied in the dung; in fact, the increased yield of potass over that without manure amounted, on both plots, to only about half that estimated to be supplied. It would appear that the residue of the potass of the dung, which we know to be but little subject to drainage, was nevertheless but slowly available to the succeeding crops. Of phosphoric acid, again, there was very much less increased amount taken up under the influence of the ammonia-salts than there was of either sulphuric acid or chlorine, both of which were so liberally supplied. It was probable that, of both the potass 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.

Of nitrogen, there was a somewhat higher percentage in the dry substance of the produce with, than in that without, the application of ammonia-salts, but still less than in that without manure, which contained so much more leguminous and miscellaneous herbage. Of total mineral matter, there was a lower percentage with than without the ammonia-salts. Of magnesia and of sulphuric acid, but especially of soda and of chlorine, the percentage was higher in the dry substance of the hay grown with the ammonia-salts; but of lime, and of phosphoric acid, the percentage was less, and of potass and silica (especially in the later years) it was very much less, under the influence of the ammonia-salts.

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 would, at the same time, appear, that where the ammonia-salts were applied, in amount supplying only 41 lbs. of nitrogen per acre per annum, the available supply of nitrogen was relatively higher than the available supply of some of the more important of the mineral constituents, more especially of potass and phosphoric acid, notwithstanding (to say nothing of the stores of the soil itself) the large residue of these estimated to have accumulated, and to remain, within the soil.

It will be remembered it was estimated that, over the eight years of the application of the dung alone, only about $10\frac{1}{2}$ per cent. of the supplied nitrogen was recovered as increase in the crop during that period, and that little more than 18 per cent. of the eight years' supply was recovered in the 20 years. In a similar way, it was estimated that, over the eight years of the application of both the farmyard manure and the ammonia-salts, about 13 per cent. of the total nitrogen supplied was recovered, and over the 20 years—eight with dung and ammonia-salts, and 12 with ammonia-salts alone—about $21\frac{1}{2}$ per cent.; or, if the increased yield of nitrogen with the ammonia-salts over that without them be assumed to represent the amount derived from them, it would result that about $27\frac{1}{2}$ per cent. of the nitrogen of the ammonia-salts was recovered, whilst only about 18 per cent. of that of the farmyard manure was recovered. It should be observed, however, that much more than $27\frac{1}{2}$ per cent. of the nitrogen of ammonia-salts, or of nitrate of soda, is estimated to be recovered when these were employed in conjunction with an annual supply of soluble artificial mineral manures.

There is thus, here, further evidence of the much less effect of a given amount of nitrogen supplied in farmyard manure than as ammonia-salts. 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.

THE SECOND CROPS.

So far, the produce of the first crops only, of each year, has been taken into account. As already explained (pp. 7 and 8), the second crops were, as a rule, fed off by sheep, having no other food, that they might contribute nothing in their manure that they had not derived from the land; whilst, having no other food, they sometimes even lost weight, especially in bad weather. They would, therefore, generally retain but little, and sometimes none at all, of either the nitrogen or the mineral constituents of the grass they consumed; and they might even sometimes themselves lose something. On this point it may be observed that, even if progressing favourably, they would probably retain not more than from 5 to 10 per cent. of the nitrogen of such food.

The object was, indeed, to secure that the treatment of the second crops should interfere as little as possible with the balance of constituents of the respective plots, as affected, on the one hand by the application of manure of known composition, and on the other by the removal of the first crops only, the quantity and composition of which were determined. In 15 out of the 20 years the second crops were so fed off by sheep; but, as the animals frequently suffered so much from change from better food, bad weather, or both, the plan was not always adopted in the later years of the 20, and has now been finally abandoned altogether. Thus, in the eleventh, fifteenth, eighteenth, and nineteenth seasons (1866, 1870, 1873, and 1874), the produce of aftergrass was cut, carefully spread on its own plot, and left to decay; whilst, in 1875, after the twentieth first crop had been removed, the second was cut, made into hay, removed, and weighed. In the four years in which the aftergrass was cut and spread on the land, we need not, perhaps, assume any loss of either nitrogen or mineral matter by the treatment. In the 15 seasons in which the second crops were fed off by sheep, there may have been some slight removal of those constituents; but, on the other hand, the nearly total amount returned to the land would be in a much more active manurial condition than in the cases when the produce was cut and spread on the land. Upon the whole, therefore, it is doubtless nearer the truth to assume the balance of constituents on the different plots to depend on the amounts supplied in manure, and those taken off in the first crops only, than to attempt any numerical estimate of the quantities lost by the feeding of the sheep on the plots. At the same time, it may be considered that the estimates of constituents removed in the first crops probably somewhat understate, especially in some seasons, the actual loss to the land.

Although it may thus be assumed that the chemical condition of the respective plots, so far as the actual amount of manurial constituents is concerned, would be little affected by the treatment of the second crops, it cannot be doubted that the character of the complex herbage would be influenced thereby, and differently according to the character of the manures, and of the seasons. As a means of forming some judgment on the point, botanical notes were generally made on the growing second crops; and, in order to arrive at some estimate of the actual and relative amounts of aftergrass, whenever the second crops were fed off by sheep, a given number of animals was allotted to each plot, according to its produce, penned on a portion of it, and the fold extended day by day as the grass was eaten down. In this way data were obtained for calculating how many sheep would be maintained per acre, for one week, on each plot; and, assuming that they would, on an average, consume grass equal to 16 lbs. of hay per head per week, the quantity of aftergrass, reckoned as hay, was estimated. The results so obtained are, of course, only approximations to the truth; but such they are; and they may be taken as at any rate giving some idea of the actual and relative amounts of growth on the different plots, and in the different seasons. Appendix-Table II. (p. 408), gives the so-estimated amounts of second crop, on each plot, in each season. But the general character and bearing of the results will be sufficiently brought to view in the following abstract table (XXVIII.), in which are given those for a selection of the plots only, representing very characteristically different conditions of manuring. The plots for which the results are given are—

Plot 3. Unmanured, every year.

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

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

Plot 11. Mixed mineral manure (including potass), and 800 lbs. ammonia-salts.

Plot 14. Mixed mineral manure (including potass), 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 as 100 ; and, at the bottom of the table are given 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 20, in every one of which the second crops were fed off 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 20) in which the second crops were cut, removed, and weighed. There are also given, at the foot of the table, the particulars of the produce, for the same plots, for the three years subsequent to the first 20.

TABLE XXVIII.—Actual amounts of the first crops of Hay, estimated amounts of the second crops, and proportion of the second to the first as 100, on selected plots.

Years.	Hay per acre, per annum.														
	Plot 3. Unmanured, continuously.			Plot 7. Mixed mineral manure (with potass), every year.			Plot 9. As Plot 7, and 400 lbs. ammonia-salts.			Plot 11. As Plot 7, and 800 lbs.* ammonia-salts.			Plot 14. As Plot 7, and 550 lbs. nitrate soda.		
	Actual first crops.	Estimated second crops.	Second to first as 100.	Actual first crops.	Estimated second crops.	Second to first as 100.	Actual first crops.	Estimated second crops.	Second to first as 100.	Actual first crops.	Estimated second crops.	Second to first as 100.	Actual first crops.	Estimated second crops.	Second to first as 100.
20 YEARS, 1856–1875 INCLUSIVE.															
	lbs.	lbs.	Per cent.	lbs.	lbs.	Per cent.	lbs.	lbs.	Per cent.	lbs.	lbs.	Per cent.	lbs.	lbs.	Per cent.
1856	2515	1188	47·2	3439	1280	37·3	6363	1507	23·7	6970	2013	28·9	..	..	..
1857	2856	950	32·3	3666	1485	40·5	6422	1645	25·6	6940	2195	31·6	..	..	..
1858	2472	1098	44·1	4082	1373	33·6	7172	1645	22·9	7508	2195	29·2	5646	1645	29·1
1859	2540	914	36·0	3416	1234	36·1	6198	1234	19·9	7150	1646	23·0	6072	960	15·8
1860	2760	2112	76·5	3928	2378	60·5	5624	2434	43·3	5744	2434	42·4	5586	2010	36·0
1861	2844	1426	50·1	4488	1782	39·7	6316	1902	30·1	6710	2021	30·1	5892	1728	29·3
1862	3052	1718	56·3	4424	1901	43·0	6402	1883	29·4	7114	2725	38·3	5718	2304	40·3
1863	2284	822	36·0	3870	1206	31·2	6026	1082	18·0	8364	1462	17·5	6528	603	9·2
1864	2688	549	20·4	4130	693	16·8	5628	869	15·4	7426	869	11·7	6816	1029	15·1
1865	1296	1462	112·8	2540	1600	63·0	3866	1234	31·9	6024	2742	45·5	5292	1603	30·3
1866	2660	..	..	4180	..	..	4956	..	..	8092	..	..	6576	..	..
1867	3332	1098	33·0	4458	1645	36·9	5382	1645	30·6	5808	2194	37·8	7183	768	10·7
1868	1960	460	23·5	4264	1024	24·0	6622	1024	15·5	7616	1280	16·8	7728	1029	13·3
1869	4256	1098	25·8	6124	1462	23·9	7700	1280	16·6	8610	1472	17·1	8526	1115	13·1
1870	644	..	..	1968	..	..	3306	..	..	5150	..	..	6300	..	..
1871	2844	1646	57·9	4414	1886	42·7	6576	1920	29·2	6856	2400	35·0	6930	3291	47·5
1872	1644	2011	122·3	4236	1920	45·3	5658	1874	33·1	7143	2149	30·1	6215	1371	22·0
1873	1372	..	..	3892	..	..	4984	..	..	5782	..	..	5796	..	..
1874	1412	..	..	3088	..	..	3290	..	..	3540	..	..	5484	..	..
1875†	2236	1384	61·9	4560	2684	58·8	5828	2729	46·8	5976	5132	85·9	7026	1974	28·1
AVERAGES.															
8 years, 1856–1863	2665	1279	48·0	3913	1580	40·4	6315	1667	26·4	7063	2086	29·5	5907‡	1542‡	26·1‡
8 years, 1864, '65, '67, '68, '69, '71, '72, and '75	2532	1213	47·9	4341	1614	37·2	5908	1572	26·6	6932	2280	32·9	6965	1522	21·9
16 years, 1856 =	2599	1246	47·9	4127	1597	38·7	6111	1619	26·5	6997	2183	31·2	6512§	1531§	23·5§
SUBSEQUENT YEARS.															
1876	1384	..	..	3886	..	..	5604	..	..	6858	..	..	7206	..	..
1877†	2364	1960	82·9	5100	2674	52·4	6054	2448	40·4	7648	4632	60·6	6258	2124	33·9
1878†	1848	1496	80·9	3926	2532	64·5	6290	2707	43·0	6260	4426	70·7	5382	1692	31·4

* 400 lbs. only in 1859, 1860, and 1861.
‡ Averages of 6 years only, 1858–1863.
† Second crops cut, removed, and weighed.
§ Averages of 14 years only, 1858–1863, and 1864, '65, '67, '68, '69, '71, '72, and '75.

We need not forestall, or incur the necessity of repetition, by discussing here the climatic characters of the different seasons. It will be sufficient to call attention to the very great variation in the estimated second, as in the actual first crops, from year to year, under the influence of the same manurial conditions. But reference to the columns showing the proportion of the second crops to the first each year will show that it sometimes varied very considerably. It is obvious that, a deficiency of rain, or a relatively too high, or too low, or too great a range of, temperature, during the spring and early summer, would give a deficient first crop, and leave the land correspondingly less exhausted. If then, the summer and autumn were favourable for growth, the second crop would have the additional advantage of unexhausted manurial condition of land. If, on the other hand, the earlier period were favourable for luxuriant first crop, the land would be comparatively exhausted for the second, even with suitable climatal conditions for its growth. And if, to add to exhaustion by the first crop, the succeeding climatal conditions are unfavourable for second growth, we shall have a still lower amount, and proportion, of second crop. Again, if both first and second crops are heavy, or the second only is heavy, in any particular season, this will have some effect, not only on the botany, and the general character, of the vegetation, but more or less on the condition of the land also, for the growth of the first crop the next year.

The results recorded in the table illustrate the great variation in the conditions referred to, from season to season. In regard to the amounts of second crop indicated by the estimates, it may be observed that, judging from the actual weights of the second crops obtained in 1875, 1877, and 1878, it may be concluded that the previously estimated amounts were more probably too low than too high; though it is true that these later seasons were more favourable for second growth than the majority of the earlier ones, for which estimates only were made. In fact, it was partly on account of the luxuriance of the second crops of these later years, that it was decided to cut and remove them from the land. It is probable, however, that a larger amount of the dry substance of the deficiently matured second, than of the better matured first crops of grass, would be required as food, and that therefore the estimate of 16 lbs. of such hay consumed per head per week may be too low.

Turning to the summaries at the bottom of the table, it is observed that, 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 removal 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.

With the same mineral manure as on plot 7, and 400 lbs. ammonia-salts per acre per annum in addition (plot 9), the first crops average about one-and-a-half time 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. Accordingly, under the influence of the addition of the ammonia-salts, the proportion of the second crop to the first is much less than with the mineral manure alone, and in a still greater degree less than without manure. 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.

With, besides the mineral manure, nitrate of soda containing approximately the same amount of nitrogen as the 400 lbs. of ammonia-salts, 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 cases of plot 9 with the mixed mineral manure and ammonia-salts, and of plot 14 with the mixed mineral manure and nitrate of soda, the amount of nitrogen applied was sufficient to give nearly the maximum growth of first crops, but not so excessive as to give a percentage of nitrogen in the produce much higher than is normal in the almost exclusively gramineous hay; indicating, therefore, that the unrecovered amount of supplied nitrogen did not remain within the soil in a readily available condition; and hence, probably, in part, the comparatively little increase of growth of second crop. In the case of plot 11, however, with double the amount of ammonia-salts of plot 9, we have 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. It will be seen further on, however, that the percentage of both mineral matter and nitrogen is generally much higher in the dry substance of the second and less matured produce, than in that of the first and more matured. The removal of the second crops, indeed, is a considerably greater drain upon the resources of the soil than might be judged 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.

In the foregoing discussion of the produce of both the first and the second crops of hay, the influence of variation in the climatal characters of the different seasons has been disregarded as far as practicable, with the object of bringing to view as prominently as possible the characteristic effects of the different manures as shown by the results obtained over series of various seasons. The object now will be to endeavour to trace the connexion 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 connexion between the characters of the weather as to moisture, heat, and light, and the luxuriance or the scantiness of vegetation. When, however, we come to compare the amounts of growth in different seasons with the usual meteorological records of the period, we at once discern how complicated is the connexion, and how inadequate are such records for a full explanation of the differences of result obtained in different seasons.

As we have said elsewhere: "It is obvious that different seasons will differ almost infinitely at each succeeding period of their advance, and that, with each variation, the character of development of the plant will also vary, tending to luxuriance, or to maturation, that is, to quantity, or to quality, as the case may be. Hence, only a very detailed consideration of climatic statistics, taken together with careful periodic observations in the field, can afford a really clear perception of the connexion between the ever-fluctuating characters of season and the equally fluctuating characters of growth and produce. It is, in fact, the distribution of the various elements making up the season, their mutual adaptations, and their adaptation to the stage of growth of the plant, which throughout influence the tendency to produce quantity or quality. It not unfrequently happens, too, that some passing conditions, not indicated by a summary of the meteorological registry, may affect the crop very strikingly; and thus the cause will be overlooked, unless careful observations be also made, and the stage of progress, and tendencies of growth, of the crop itself at the time, be likewise taken into account." Again: "Those characters of season which are very unfavourable for land in poor condition, may be favourable to land in high condition, and *vice versâ*."

If such be the difficulty and the intricacy of the subject when the growth of a crop consisting of a single species only is concerned, how much more difficult and intricate must it be when we have 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, under 20, or 50 or more, according to the varied manurial conditions provided?

Still, it will be of interest to show the fluctuations of produce from season to season, side by side with those in the characters of the seasons themselves, so far as such records as we have at command bearing upon the subject enable us to do so. It would, however, occupy far too much space to attempt to point out the connexion between the amount of produce and the climatal conditions of each individual season. It must suffice in this place 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 Part II., relating to the Botanical Results, the connexion between climatal conditions and growth will be further brought to view, in discussing the characters of the seasons and the amounts and the characters of the growth, in the four years in which the botanical analysis of the mixed produce was undertaken.

Throughout the whole period of the experiments on mixed herbage, and for some years prior to their commencement, the rainfall has been registered at Rothamsted. At first the temperature also was observed, but owing to the difficulty of securing the completeness of the record throughout the year, the observations were abandoned. We are obliged to fall back, therefore, on the published records of the observations at Greenwich Observatory; which, though obviously inapplicable for the discussion of the subject in much detail, nevertheless sufficiently clearly indicate, for our present limited purpose, the distinctive and comparative characters of the different seasons, or parts of seasons, so far as temperature is concerned. With regard to light, there are not wanting so-called actinometric observations of various kinds; and there have also been of late years diurnal records of the number of hours of sunshine. There is, too, reason to hope that methods of systematic observation and record will before long be perfected and simplified; and that, at no very distant future, data relating to the quantity and quality of the sunlight at different seasons of the year, or in different years, may be available as another element in the study of the connexion between meteorological influences and vegetation. In the meantime, comparative temperature is the most reliable basis we possess for any deductions as to the comparative amounts of effective sunlight, as between one and the same period of different years; but it is obviously less directly applicable for the purpose of drawing conclusions as between different periods of the same season.

In Appendix-Tables III. to IX. (pp. 409 to 415), are given, for each year of the first 20, and also for each of the three subsequent years—

In Table III., the actual amounts of produce of hay per acre (first crops) on five selected plots, and the indices of those amounts.

In Table IV., the monthly rainfall in inches (at Rothamsted).

In Table V., the number of days in each month when the rainfall exceeded 0·01 inch.

In Table VI., the monthly mean maximum temperature (at Greenwich).

In Table VII., the monthly mean minimum temperature (at Greenwich).

In Table VIII., the monthly mean temperature (at Greenwich).

In Table IX., the monthly mean range of temperature (at Greenwich).

And, in the respective tables, there are given, for each season, the total rainfall, the total number of days on which 0·01 inch, or more, fell, and the means for each item of temperature—

1. For the total 12 months; July to June inclusive.
2. For four months—July, August, September, and October;
3. For four months—November, December, January, and February;
4. For four months—March, April, May, and June;
5. For three months—April, May, and June;
6. For two months—April and May.

It should be explained that, in Appendix-Table III., relating to produce, that of the same very characteristically differently manured plots is selected for illustration, as in the case of the consideration of the second crops; in the left-hand columns of the table the actual amounts of produce of each plot are given, and in the right-hand columns the indices of these amounts—that is to say, for each plot the highest amount of produce in any one year of the 20 is set down as 1, the second highest amount as 2, and so on.

An examination of the columns of indices of produce will show that, with each of the five very different conditions of manuring, 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 has been fully considered already (p. 334, *et seq.*). There can be no hesitation, therefore, in taking the season of 1869 as that of the highest productiveness of the 20, and that of 1870 (with the exception mentioned) as one of the lowest productiveness; the next in order in this respect being 1874. It will be interesting to compare the produce in these two most contrasted seasons, 1869 and 1870, and also the characters of the seasons themselves.

In Table XXIX. are given, for each of the selected plots, the average produce (of first crops) over the 20 years; the produce in 1869; the produce in 1870; the difference in amount over (+), or under (—), the average of the 20 years; and the deficiency in 1870 compared with 1869.

TABLE XXIX.—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, continuously.	Plot 7. Mixed mineral manure, alone.	Plot 9. Mixed mineral manure, and 400 lbs. ammonia-salts.	Plot 11. Mixed mineral manure, and 800 lbs.* ammonia-salts.	Plot 14. Mixed mineral manure, and 550 lbs. nitrate soda.	Means.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Average 20 years, 1856–1875 .	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
1870–1869.	−3612	−4156	−4394	−3460	−2226	−3569

The next Table (XXX.) shows some of the meteorological conditions under which the two very different crops were grown. The particulars are given—for each of the 12 months from July to June separately, and for series of months collectively, for the average of the 20 years, for 1868–1869, and for 1869–1870. The variations of each of the two seasons + or − the average, and the variations of 1869–1870, the year of lowest produce, + or − 1868–1869, the year of highest produce, are also given.

* 400 lbs. only in 1859, 1860, and 1861.
† Average of 18 years only, 1858–1875.

TABLE XXX.—Abstract of meteorological conditions of 1868–9, the year comparison of each with the average of 20

	Monthly.							
	July.	August.	September.	October.	November.	December.	January.	February.
RAINFALL AT ROTHAMSTED.—INCHES.								
Average 20 years, 1855-6–1874-5	2·46	2·49	2·51	3·07	1·99	2·04	2·79	1·57
1868–1869	0·37	3·77	2·80	2·04	0·42	4·55	3·44	2·41
1869–1870	0·97	1·35	2·79	2·05	2·38	3·20	1·81	2·10
1868-9 + or − average of 20 years	−2·09	+1·28	+0·29	−1·03	−1·57	+2·51	+0·65	+0·84
1869-70 + or − average of 20 years	−1·49	−1·14	+0·28	−1·02	+0·39	+1·16	−0·98	+0·53
1869-70 + or − 1868-9	+0·60	−2·42	−0·01	+0·01	+1·96	−1·35	−1·63	−0·31
RAINFALL AT ROTHAMSTED.—NUMBER OF DAYS WHEN 0·01 INCH, OR MORE, FELL.								
Average 20 years, 1855-6–1874-5	12	13	13	16	14	14	16	12
1868–1869	4	15	9	11	8	22	14	16
1869–1870	6	11	12	17	12	18	17	21
1868-9 + or − average of 20 years	−8	+2	−4	−5	−6	+8	−2	+4
1869-70 + or − average of 20 years	−6	−2	−1	+1	−2	+4	+1	+9
1869-70 + or − 1868-9	+2	−4	+3	+6	+4	−4	+3	+5
MEAN MAXIMUM TEMPERATURE AT GREENWICH (FAHRENHEIT).								
Average 20 years, 1855-6–1874-5	75·2	73·5	67·9	59·0	48·3	44·4	43·8	46·1
1868–1869	82·0	75·1	71·7	56·9	46·9	50·5	46·0	51·8
1869–1870	77·0	72·3	68·6	57·5	49·1	42·0	42·6	41·4
1868-9 + or − average of 20 years	+6·8	+1·6	+3·8	−2·1	−1·4	+6·1	+2·2	+ 5·7
1869-70 + or − average of 20 years	+1·8	−1·2	+0·7	−1·5	+0·8	−2·4	−1·2	− 4·7
1869-70 + or − 1868-9	−5·0	−2·8	−3·1	+0·6	+2·2	−8·5	−3·4	−10·4
MEAN MINIMUM TEMPERATURE AT GREENWICH (FAHRENHEIT).								
Average 20 years, 1855-6–1874-5	53·2	53·0	49·4	44·1	36·7	35·0	34·0	34·7
1868–1869	55·7	55·0	51·1	40·2	36·1	41·1	36·5	39·7
1869–1870	54·5	52·4	52·4	42·0	37·4	33·4	34·0	31·9
1868-9 + or − average of 20 years	+2·5	+2·0	+1·7	−3·9	−0·6	+6·1	+2·5	+5·0
1869-70 + or − average of 20 years	+1·3	−0·6	+3·0	−2·1	+0·7	−1·6	0·0	−2·8
1869-70 + or − 1868-9	−1·2	−2·6	+1·3	+1·8	+1·3	−7·7	−2·5	−7·8
MEAN TEMPERATURE AT GREENWICH (FAHRENHEIT).								
Average 20 years, 1855-6–1874-5	62·6	61·7	57·4	50·6	42·2	39·8	38·8	39·8
1868–1869	67·5	63·6	60·5	47·9	41·5	46·0	41·1	45·3
1869–1870	64·5	60·8	59·0	48·9	43·0	37·9	38·3	36·2
1868-9 + or − average of 20 years	+4·9	+1·9	+3·1	−2·7	−0·7	+6·2	+2·3	+5·5
1869-70 + or − average of 20 years	+1·9	−0·9	+1·6	−1·7	+0·8	−1·9	−0·5	−3·6
1869-70 + or − 1868-9	−3·0	−2·8	−1·5	+1·0	+1·5	−8·1	−2·8	−9·1
MEAN RANGE OF TEMPERATURE AT GREENWICH (FAHRENHEIT).								
Average 20 years, 1855-6–1874-5	22·0	20·5	18·5	14·9	11·8	9·6	9·6	11·4
1868–1869	26·3	20·1	20·6	16·7	10·8	9·4	9·5	12·1
1869–1870	22·5	19·9	16·2	15·5	11·7	8·6	8·6	9·5
1868-9 + or − average of 20 years	+4·3	−0·4	+2·1	+1·8	−1·0	−0·2	−0·1	+0·7
1869-70 + or − average of 20 years	+0·5	−0·6	−2·3	+0·6	−0·1	−1·0	−1·0	−1·9
1869-70 + or − 1868-9	−3·8	−0·2	−4·4	−1·2	+0·9	−0·8	−0·9	−2·6

of highest productiveness; of 1869–70, the year of lowest productiveness; years; and comparison of the one with the other.

Monthly (continued).				12 months, July to June, inclusive.	4 months, July, August, September, October.	4 months, November, December, January, February.	4 months, March, April, May, June.	3 months, April, May, June.	2 months, April and May.
March.	April.	May.	June.						
Rainfall at Rothamsted.—Inches (continued).									
1·67	1·86	2·20	2·50	27·15	10·53	8·39	8·23	6·56	4·06
1·48	2·13	3·23	1·07	27·71	8·98	10·82	7·91	6·43	5·36
1·81	0·46	1·35	0·98	21·25	7·16	9·49	4·60	2·79	1·81
−0·19	+0·27	+1·03	−1·43	+0·56	−1·55	+2·43	−0·32	−0·13	+1·30
+0·14	−1·40	−0·85	−1·52	−5·90	−3·37	+1·10	−3·63	−3·77	−2·25
+0·33	−1·67	−1·88	−0·09	−6·46	−1·82	−1·33	−3·31	−3·64	−3·55
Rainfall at Rothamsted.—Number of Days when 0·01 inch, or more, fell (continued).									
13	11	12	12	158	54	56	48	35	24
16	12	16	8	151	39	60	52	36	28
15	8	10	5	152	46	68	38	23	18
+3	+1	+4	−4	−7	−15	+ 4	+ 4	+ 1	+ 5
+2	−3	−2	−7	−6	− 8	+12	−10	−12	− 5
−1	−4	−6	−3	+1	+ 7	+ 8	−14	−13	−10
Mean Maximum Temperature at Greenwich (Fahrenheit) (continued).									
49·9	58·6	64·4	71·3	58·5	68·9	45·7	61·1	64·8	61·5
44·8	61·6	60·7	67·4	59·6	71·4	48·8	58·6	63·2	61·2
46·9	62·0	66·9	74·8	58·4	68·9	43·8	62·7	67·9	64·5
−5·1	+3·0	−3·7	−3·9	+1·1	+2·5	+3·1	−2·5	−1·6	−0·3
−3·0	+3·4	+2·5	+3·5	−0·1	0·0	−1·9	+1·6	+3·1	+3·0
+2·1	+0·4	+6·2	+7·4	−1·2	−2·5	−5·0	+4·1	+4·7	+3·3
Mean Minimum Temperature at Greenwich (Fahrenheit) (continued).									
35·4	39·6	43·9	50·2	42·4	50·0	35·1	42·3	44·6	41·8
32·3	41·8	43·7	46·0	43·3	50·5	38·4	41·0	43·8	42·8
34·0	38·4	42·0	50·7	41·9	50·3	34·2	41·3	43·7	40·2
−3·1	+2·2	−0·2	−4·2	+0·9	+0·5	+3·3	−1·3	−0·8	+1·0
−1·4	−1·2	−1·9	+0·5	−0·5	+0·3	−0·9	−1·0	−0·9	+1·6
+1·7	−3·4	−1·7	+4·7	−1·4	−0·2	−4·2	+0·3	−0·1	−2·6
Mean Temperature at Greenwich (Fahrenheit) (continued).									
41·7	47·7	52·8	58·8	49·5	58·1	40·2	50·3	53·1	50·3
37·5	50·3	50·5	55·3	50·6	59·9	43·5	48·4	52·0	50·4
39·6	48·9	53·4	60·9	49·3	58·3	38·9	50·7	54·4	51·2
−4·2	+2·6	−2·3	−3·5	+1·1	+1·8	+3·3	−1·9	−1·1	+0·1
−2·1	+1·2	+0·6	+2·1	−0·2	+0·2	−1·3	+0·4	+1·3	+0·9
+2·1	−1·4	+2·9	+5·6	−1·3	−1·6	−4·6	+2·3	+2·4	+0·8
Mean Range of Temperature at Greenwich (Fahrenheit) (continued).									
14·6	19·1	20·5	21·1	16·1	19·0	10·6	18·8	20·2	19·8
12·5	19·8	17·0	21·4	16·4	20·9	10·5	17·7	19·4	18·4
12·9	23·6	24·9	24·1	16·5	18·5	9·6	21·4	24·2	24·3
−2·1	+0·7	−3·5	+0·3	+0·3	+1·9	−0·1	−1·1	−0·8	−1·4
−1·7	+4·5	+4·4	+3·0	+0·4	−0·5	−1·0	+2·6	+4·0	+4·5
+0·4	+3·8	+7·9	+2·7	+0·1	−2·4	−0·9	+3·7	+4·8	+5·9

The bottom line of Table XXIX. shows that (excluding the nitrate plot) there was an average yield per acre of nearly 4000 lbs. 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.

In the preceding year, 1868, there had been, under most conditions of manuring, and especially with high manuring, more than average first crops, but considerably less than average second crops. The very limited second growth is accounted for by the fact that there had been a great deficiency of rain in May, June, and July, with a considerable excess of temperature in each of those three months; whilst the rainfall of August and September, though in excess of the average, was still insufficient to restore the balance or to compensate for the previous drought, and there were again, in those two months, higher than average temperatures. Indeed, September 1868 ended an extraordinarily warm period of nearly nine months' duration. October and November were, throughout, with very few exceptions, colder than usual, both day and night, whilst in October there was a deficiency of rain, and in November a very great deficiency. So far, then, the period preceding the enormous growth of 1869 was unfavourable to luxuriant condition of the herbage.

From this time, however, throughout the three winter months of December, January, and February, there was a considerable excess of rain, with temperatures ranging considerably higher than the average. To go a little more into detail, December was almost throughout very much warmer than the average, with a very great excess of rain, some violent gales of wind, very variable, but upon the whole very low barometric pressures, and high degree of humidity of the atmosphere. The average temperature of December had, indeed, been exceeded only twice during the preceding 98 years, namely, in 1806 and 1852. Again, with the exception of a week after the middle of January, 1869, the very warm period continued until the end of February, completing three winter months of average temperature about six degrees higher than the average of 98 years; and, after the enormous excess of rain in December, there was again a moderate excess in both January and February. March, on the contrary, was several degrees colder than the average, with rather less than the average amount of rain. Early in April warm weather again set in, and lasted till nearly the end of the month, the temperature during this period being several degrees higher than the average, whilst the rainfall was only about the average. May and June were, with few exceptions, of short duration, very much colder than the average. Towards the end of May the cold was very extreme for the season, and the greater part of June was very unusually cold, both day and night; and there was in May a considerable excess, but in June a greater deficiency, of rain.

To sum up: after five months of unusually high temperatures, and unusual drought during the first three of them, 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.

It would thus appear that the excessive produce of grass in 1869 was by no means due alone, or even perhaps chiefly, to the climatic conditions during the limited period of really active accumulation and aboveground growth, which, in fact, were not specially favourable; but the result was due to the only moderately favourable conditions during that period, succeeding upon very favourable, instead of as usual detrimental ones, throughout the three winter months, thus bringing the herbage unusually forward, and rendering it the more capable of turning to the best account such climatic elements of growth as followed.

It may here be remarked that this result is somewhat analogous to that observed in the case of our 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.

Let us now contrast with the foregoing conditions of extremely luxuriant growth, those under which the smallest produce of the 20 years was obtained.

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 defect 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 characterised 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 20 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 very defective 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.

It may be well to notice briefly, the characters of the seasons, and of the produce, of 1868 and 1874; the former perhaps the second in order of productiveness, and the latter the second in order of unproductiveness. The following table (XXXI.) summarises, in the same form as before, the results relating to the produce of these two seasons; and Table XXXII. summarises the actual and comparative characters of the seasons themselves, also in the same form as before.

TABLE XXXI.—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. Unmanured, continuously.	Plot 7. Mixed mineral manure, alone.	Plot 9. Mixed mineral manure, and 400 lbs. ammonia salts.	Plot 11. Mixed mineral manure, and 800 lbs.* ammonia-salts.	Plot 14. Mixed mineral manure, and 550 lbs. nitrate soda.	Means.
	lbs.	lbs.	lbs.	lbs.	lbs.	
Average 20 years, 1856-1875 .	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
1874-1868	− 548	−1176	−3332	−4076	−2244	−2275

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

† Average of 18 years only, 1858–1875.

TABLE XXXII.—Abstract of meteorological conditions of 1867–8, the year second comparison of each with the average of 20

	Monthly.							
	July.	August.	September.	October.	November.	December.	January.	February.
RAINFALL AT ROTHAMSTED.—INCHES.								
Average 20 years, 1855-6–1874-5	2·46	2·49	2·51	3·07	1·99	2·04	2·79	1·57
1867–1868	4·10	2·15	2·06	1·86	0·32	2·04	3·93	1·49
1873–1874	2·54	2·69	2·38	2·83	1·99	0·71	1·93	1·73
1867–8 + or – average of 20 years	+1·64	–0·34	–0·45	–1·21	–1·67	0·00	+1·14	–0·08
1873–4 + or – average of 20 years	+0·08	+0·20	–0·13	–0·24	0·00	–1·33	–0·86	+0·16
1873–4 + or – 1867–8	–1·56	+0·54	+0·32	+0·97	+1·67	–1·33	–2·00	+0·24
RAINFALL AT ROTHAMSTED.—NUMBER OF DAYS WHEN 0·01 INCH, OR MORE, FELL.								
Average 20 years, 1855-6–1874-5	12	13	13	16	14	14	16	12
1867–1868	17	9	7	17	9	10	13	11
1873–1874	10	19	12	22	19	12	18	16
1867–8 + or – average of 20 years	+5	– 4	–6	+1	– 5	–4	–3	–1
1873–4 + or – average of 20 years	–2	+ 6	–1	+6	+ 5	–2	+2	+4
1873–4 + or – 1867–8	–7	+10	+5	+5	+10	+2	+5	+5
MEAN MAXIMUM TEMPERATURE AT GREENWICH (FAHRENHEIT).								
Average 20 years, 1855-6–1874-5	75·2	73·5	67·9	59·0	48·3	44·4	43·8	46·1
1867–1868	71·1	73·3	68·0	57·2	47·8	42·2	41·4	49·9
1873–1874	76·6	74·7	65·2	57·0	50·1	45·6	47·3	45·0
1867–8 + or – average of 20 years	–4·1	–0·2	+0·1	–1·8	–0·5	–2·2	–2·4	+3·8
1873–4 + or – average of 20 years	+1·4	+1·2	–2·7	–2·0	+1·8	+1·2	+3·5	–1·1
1873–4 + or – 1867–8	+5·5	+1·4	–2·8	–0·2	+2·3	+3·4	+5·9	–4·9
MEAN MINIMUM TEMPERATURE AT GREENWICH (FAHRENHEIT).								
Average 20 years, 1855-6–1874-5	53·2	53·0	49·4	44·1	36·7	35·0	34·0	34·7
1867–1868	50·8	53·4	50·3	42·0	35·3	32·1	32·8	36·8
1873–1874	53·9	54·4	46·1	40·6	38·8	35·2	36·2	33·5
1867–8 + or – average of 20 years	–2·4	+0·4	+0·9	–2·1	–1·4	–2·9	–1·2	+2·1
1873–4 + or – average of 20 years	+0·7	+1·4	–3·3	–3·5	+2·1	+0·2	+2·2	–1·2
1873–4 + or – 1867–8	+3·1	+1·0	–4·2	–1·4	+3·5	+3·1	+3·4	–3·3
MEAN TEMPERATURE AT GREENWICH (FAHRENHEIT).								
Average 20 years, 1855-6–1874-5	62·6	61·7	57·4	50·6	42·2	39·8	38·8	39·8
1867–1868	59·4	62·0	57·6	48·7	41·1	37·5	37·2	43·0
1873–1874	63·4	62·7	54·7	47·8	44·2	40·6	41·7	38·7
1867–8 + or – average of 20 years	–3·2	+0·3	+0·2	–1·9	–1·1	–2·3	–1·6	+3·2
1873–4 + or – average of 20 years	+0·8	+1·0	–2·7	–2·8	+2·0	+0·8	+2·9	–1·1
1873–4 + or – 1867–8	+4·0	+0·7	–2·9	–0·9	+3·1	+3·1	+4·5	–4·3
MEAN RANGE OF TEMPERATURE AT GREENWICH (FAHRENHEIT).								
Average 20 years, 1855-6–1874-5	22·0	20·5	18·5	14·9	11·8	9·6	9·6	11·4
1867–1868	20·3	19·9	17·7	15·2	12·5	10·1	8·6	13·1
1873–1874	22·7	20·3	19·1	16·4	11·3	10·4	11·1	11·5
1867–8 + or – average of 20 years	–1·7	–0·6	–0·8	+0·3	+0·7	+0·5	–1·0	+1·7
1873–4 + or – average of 20 years	+0·7	–0·2	+0·6	+1·5	–0·5	+0·8	+1·5	+0·1
1873–4 + or – 1867–8	+2·4	+0·4	+1·4	+1·2	–1·2	+0·3	–2·5	–1·6

in order of productiveness; of 1873–4, the year second in order of unproductiveness; years; and comparison of the one with the other.

Monthly—continued.				12 months, July to June, inclusive.	4 months, July, August, September, October.	4 months, November, December, January, February.	4 months, March, April, May, June.	3 months, April, May, June.	2 months, April and May.
March.	April.	May.	June.						
Rainfall at Rothamsted.—Inches (continued).									
1·67	1·86	2·20	2·50	27·15	10·53	8·39	8·23	6·56	4·06
1·92	2·19	0·73	0·37	23·16	10·17	7·78	5·21	3·29	2·92
0·65	2·14	1·19	1·59	22·37	10·44	6·36	5·57	4·92	3·33
+0·25	+0·33	−1·47	−2·13	−3·99	−0·36	−0·61	−3·02	−3·27	−1·14
−1·02	+0·28	−1·01	−0·91	−4·78	−0·09	−2·03	−2·66	−1·64	−0·73
−1·27	−0·05	+0·46	+1·22	−0·79	+0·27	−1·42	+0·36	+1·63	+0·41
Rainfall at Rothamsted.—Number of Days when 0·01 inch, or more, fell (continued).									
13	11	12	12	158	54	56	48	35	24
13	10	6	4	126	50	43	33	20	16
14	10	11	13	176	63	65	48	34	21
0	−1	−6	−8	−32	− 4	−13	−15	−15	−7
+1	−1	−1	+1	+18	+ 9	+ 9	0	− 1	−2
+1	0	+5	+9	+50	+13	+22	+15	+14	+5
Mean Maximum Temperature at Greenwich (Fahrenheit) (continued).									
49·9	58·6	64·4	71·3	58·5	68·9	45·7	61·1	64·8	61·5
52·9	58·8	70·5	76·3	59·1	67·4	45·4	64·6	68·5	64·7
52·8	61·5	63·2	71·1	59·2	68·4	47·0	62·2	65·3	62·4
+3·0	+0·2	+6·1	+5·0	+0·6	−1·5	−0·3	+3·5	+3·7	+3·2
+2·9	+2·9	−1·2	−0·2	+0·7	−0·5	+1·3	+1·1	+0·5	+0·9
−0·1	+2·7	−7·3	−5·2	+0·1	+1·0	+1·6	−2·4	−3·2	−2·3
Mean Minimum Temperature at Greenwich (Fahrenheit) (continued).									
35·4	39·6	43·9	50·2	42·4	50·0	35·1	42·3	44·6	41·8
36·8	40·1	46·1	50·8	42·3	49·1	34·3	43·5	45·7	43·1
36·6	41·3	40·7	48·3	42·1	48·8	35·9	41·7	43·4	41·0
+1·4	+0·5	+2·2	+0·6	−0·1	−0·9	−0·8	+1·2	+1·1	+1·3
+1·2	+1·7	−3·2	−1·9	−0·3	−1·2	+0·8	−0·6	−1·2	−0·8
−0·2	+1·2	−5·4	−2·5	−0·2	−0·3	+1·6	−1·8	−2·3	−2·1
Mean Temperature at Greenwich (Fahrenheit) (continued).									
41·7	47·7	52·8	58·8	49·5	58·1	40·2	50·3	53·1	50·3
44·0	48·1	57·3	62·0	49·8	56·9	39·7	52·9	55·8	52·7
43·7	50·0	50·5	58·0	49·7	57·2	41·3	50·6	52·8	50·3
+2·3	+0·4	+4·5	+3·2	+0·3	−1·2	−0·5	+2·6	+2·7	+2·4
+2·0	+2·3	−2·3	−0·8	+0·2	−0·9	+1·1	+0·3	−0·3	0·0
−0·3	+1·9	−6·8	−4·0	−0·1	+0·3	+1·6	−2·3	−3·0	−2·4
Mean Range of Temperature at Greenwich (Fahrenheit) (continued).									
14·6	19·1	20·5	21·1	16·1	19·0	10·6	18·8	20·2	19·8
16·1	18·7	24·4	25·5	16·8	18·3	11·1	21·2	22·9	21·5
16·2	20·2	22·5	22·8	17·0	19·6	11·1	20·4	21·8	21·3
+1·5	−0·4	+3·9	+4·4	+0·7	−0·7	+0·5	+2·4	+2·7	+1·7
+1·6	+1·1	+2·0	+1·7	+0·9	+0·6	+0·5	+1·6	+1·6	+1·5
+0·1	+1·5	−1·9	−2·7	+0·2	+1·3	0·0	−0·8	−1·1	−0·2

A comparison of Table XXXI. with Table XXIX. will show that the excess of produce over the average was very much less in 1868 than in 1869, and that it was the most considerable under the influence of highly nitrogenous in conjunction with mineral manures. Indeed, with mineral manures alone (plot 7) the increase was very small, and without manure there was even a considerable deficiency in this season, which nevertheless is taken as, upon the whole, illustrative of high productiveness. There are, in fact, other seasons giving more produce on one or other of the plots; but, excepting 1869, there is no other that gives so much on each of the three selected highly-manured plots. The season was, therefore, one of great luxuriance with high manuring, but of deficient growth with low manuring.

The season of 1874 gave more uniformly bad results than did that of 1868 give uniformly good ones; the produce being the twentieth, or lowest, in order of amount on two of the highly-manured plots, seventeenth on the third, eighteenth on the mineral manured, and seventeenth on the unmanured plot.

The difference between the produce of the two seasons was the most marked where ammonia-salts were used; there being about 1½ ton less hay in 1874 than in 1868 where the smaller amount of ammonia-salts was applied (plot 9), and nearly 2 tons less with the larger amount (plot 11); whilst, with the nitrate of soda, the produce in the reputed good season was only about 1 ton more than in the reputed bad one. This was due, however, not to any deficiency of growth with the nitrate in the good season, but to much better growth with it than with the ammonia-salts in the bad season—a result explained by the fact of the less dependence of the herbage growing under the influence of the nitrate on atmospheric supplies of moisture during the period of active vegetation.

In 1867, the season previous to the productive one of 1868, there had been fairly average both first and second crops. October and November were considerably deficient in rain, and both were colder than usual. December was characterised by great and rapid variations of temperature and barometric pressure, some extremely heavy gales, sometimes frost, snow, and sleet, at others very warm weather, with (in the aggregate) a fair amount of total fall. Nearly the first half of January (1868) was also very cold, but from that time to the end of the summer the weather was unusually warm. February, March, April, May, and June, were, indeed, all considerably warmer than the average. The average temperature of April had, however, frequently, and that of May and June occasionally, been exceeded in the corresponding months of other years; but the average temperature of the three months together had only once been exceeded in any corresponding three months in 98 years—namely, in 1865—when, though April was hotter, May and June were not quite so hot; and the average temperature of the whole period from the middle of January to the end of June was only exceeded in 1822. Concurrently with this long-continued warm weather, there was a considerable excess of rain in January, with in the early part of the month several gales of wind; there was scarcely the average fall in February, a slight excess in March and April, a great deficiency in May, and a still greater in June. The degree of humidity of the atmosphere was also below the average in each of the six months, January to June inclusive.

With the excess of rain in January, the fair amounts in February, March, and April, and the unusual warmth of those early spring months, vegetation became active very early, and was very forward before the dry, and very hot, weather of May and June set in. The result was, as Table XXXI. shows, that with liberal manuring there were very heavy crops, which fully matured, and were cut very early; whilst, without manure, or with only mineral manure, the herbage suffered greatly from the heat and drought of May and June.

Thus, 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.

We have, it may be observed, the curious result of the lowest produce of the 20 years in the year of 1870, which was the one of the most extreme heat and drought of the series, and of the highest produce but one in 1868, which was only second to 1870 in heat and drought of the growing period. But there was this difference between the two seasons: 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 is, a month later than in 1870, and when with high manuring the herbage was already very luxuriant—that the heat and drought succeeded, then serving to elaborate and mature, rather than materially to check, vegetation in such condition of luxuriance and forwardness.

Let us now call attention to the characters of the season of 1874, the second of the 20 in order of unproductiveness. The preceding season (1873) had been one of less than average productiveness of first crops, but of fairly luxuriant second growth, which was cut twice—namely, about the middle of August, and after the middle of October—and the produce was, in each case, spread on the respective plots to decay.

In every month, from September, 1873, to June, 1874, inclusive, excepting in February, and April (when the excess was only slight), there was more or less defect of rain compared with the average of the 20 years, and in December, January, March, May, and June, the deficiency was very considerable. With this marked deficiency of rain almost throughout both the earlier and the later periods of the grass season, the months of November, December, and January, and again of March and April, were upon the whole warmer than usual, both day and night; whilst February, May, and

June, were unseasonably cold. This was more especially the case with May, and especially so far as its night temperatures were concerned. With regard to the seven months—December, 1873, to June, 1874, inclusive—Mr. GLAISHER states that there is no instance on record of so small a fall of rain during those months collectively. And, although December, January, March, and April were, on the average, notably warmer than usual, February was on the average colder; the period from the 4th to the 12th of the month was extremely cold, as also was that from the 4th to the 13th of March, when snow was general. But it was the first three weeks of May which showed the most unseasonable reductions of temperature, the night frosts during that period being exceptionally severe; and from the middle to the end of June also the weather was very cold; whilst, throughout both May and June there was a great deficiency of rain.

Thus, although the winter and early spring of 1873–4 were upon the whole considerably warmer than usual, there were periods of considerable 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 early flowering stems were bleached, and in many cases killed. Although a number of the grasses suffered considerably, 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 leguminous, and several of the miscellaneous species, also suffered very considerably.

The four seasons which have been selected for the purpose of attempting to trace the connexion between the amount of growth of the mixed herbage of grass land, and such meteorological conditions as we have sufficient record of, most strikingly illustrate the intricacy and difficulty of the subject, as referred to in our introductory remarks. 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.

In both cases 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, until the end of April. Then followed, instead of drought and heat, drought and unusual cold, both day and night, especially the latter, and the already backward herbage was very materially damaged, yielding not only checked and stunted, but really damaged crops.

In the discussion of the characteristic effects of the different manures, it has been pointed out, in general terms, that both the botanical and the chemical composition of the mixed herbage varied very greatly 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 their condition of development and maturity. In this place, however, we have to deal with the question of the quantity rather than of the quality of the produce, and from this point of view the few illustrations of the influence of season which have been given will suffice. But, in the next section of our report—"Part II.—The Botanical Results"—the characters of the four seasons in which the botanical analyses of the produce were undertaken will be considered; and then, not only will the effects of variation of climatal conditions on the quantity of produce yielded be further elucidated, but an endeavour will be made to trace a connexion between the distinctive habits of growth of plants of different orders, genera, or species, and the way in which, accordingly, their predominance, and the amount, and the character, of their development, are influenced by the characters of the seasons.

APPENDIX-TABLE I.—Showing (taken together with the footnotes) the description and quantities from each plot, in each year,

Plots.	Manures per acre per annum (unless otherwise stated in the footnotes).	Produce of hay per acre, first crops only, first 20 years, 1856–1875. Each year. 1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.	1864.	1865.	1866.	1867.	1868.	Plots.
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1	1856–63, 8 years, 14 tons farmyard manure and 200 lbs. ammonia-salts*; 1864 and since, 200 lbs. ammonia-salts alone	5009	6008	5320	5356	5704	5320	5556	6028	6216	3616	4968	5880	4676	1
2	1856–63, 8 years, 14 tons farmyard manure; 1864 and since, unmanured	4030	5328	4164	4584	5208	5052	5060	5004	5392	2848	4816	5716	4116	2
3	Unmanured continuously	2515	2856	2472	2540	2760	2844	3052	2284	2688	1296	2660	3332	1960	3
4–1	1856–58, 3 years, 2000 lbs. sawdust (average produce 2299 lbs.); 1859 and since, 3½ cwts. superphosphate of lime†	2313	2340	2244	2828	3176	3400	3252	2592	2632	1244	2884	3540	2200	4–1
4–2	1856–58, 3 years, 2000 lbs. sawdust (average produce 2299 lbs.); 1859 and since, 3½ cwts. superphosphate of lime and 400 lbs. ammonia-salts	2313	2340	2244	4996	4788	4968	4756	4356	4312	2904	3864	4352	3276	4–2
5	1856 and since, 400 lbs. ammonia-salts	4028	3774	3982	3644	2940	3808	3854	3508	2940	1722	2920	3306	2688	5
6‡	1856–68, 13 years, 400 lbs ammonia-salts; 1869–78, 300 lbs. sulph. potass, 100 lbs. sulph. soda, 100 lbs. sulph. magnesia, and 3½ cwts. superphosphate	3954	3710	4166	3664	2982	3943	4452	3412	3108	1792	3066	3192	3080	6
7	1856–78, 300 lbs. sulph. potass, 100 lbs.§ sulph. soda, 100 lbs. sulph. magnesia, and 3½ cwts. superphosphate	3429	3666	4082	3416	3928	4488	4424	3870	4130	2540	4180	4458	4264	7
8‡	1856–61, 6 years, 300 lbs. sulph. potass, 200 lbs. sulph. soda, 100 lbs. sulph. magnesia, and 3½ cwts. superphosphate; 1862 and since, 250 lbs.‖ sulph. soda, 100 lbs. sulph. magnesia, and 3½ cwts. superphosphate	3711	3994	4376	3396	4074	4608	4524	3710	3424	1894	3212	3824	3058	8
9	1856–78, 300 lbs. sulph. potass, 100 lbs.§ sulph. soda, 100 lbs. sulph. magnesia, 3½ cwts. superphosphate, and 400 lbs. ammonia-salts	6363	6422	7172	6198	5624	6316	6402	6026	5628	3866	4956	5382	6622	9
10‡	1856–61, 6 years, 300 lbs. sulph. potass, 200 lbs. sulph. soda, 100 lbs. sulph. magnesia, 3½ cwts. superphosphate, 400 lbs. ammonia-salts; 1862 and since, 250 lbs.‖ sulph. soda, 100 lbs. sulph. magnesia, 3½ cwts. superphosphate, and 400 lbs. ammonia-salts	6369	6428	6892	5852	5362	6432	6180	6582	5356	3666	4964	4984	4992	10
11–1	1856–78, 300 lbs. sulph. potass, 100 lbs.§ sulph. soda, 100 lbs. sulph. magnesia, 3½ cwts. superphosphate, and 800 lbs ¶ ammonia-salts	6970	6940	7508	7150	5744	6710	7108	8036	7152	5816	7812	5360	7140	11–1
11–2	1856–78, 300 lbs. sulph. potass, 100 lbs.§ sulph. soda, 100 lbs. sulph. magnesia, 3½ cwts. superphosphate, 800 lbs.¶ ammonia-salts, and 400 lbs. silicate of soda**	6970	6940	7508	7150	5744	6710	7120	8692	7700	6232	8372	6256	8092	11–2
12	Unmanured continuously	2351	2592	3360	2576	2884	3304	3424	2844	2808	1932	3012	3048	2676	12
13	1856–78, 300 lbs. sulph. potass, 100 lbs.§ sulph. soda, 100 lbs. sulph. magnesia, 3½ cwts. superphosphate, 400 lbs. ammonia-salts, and 2000 lbs. cut wheat straw	5412	6050	6752	6370	5698	6462	6308	7298	6594	4908	6868	6064	6832	13
14	1858–78, 550 lbs. nitrate of soda,†† 300 lbs. sulph. potass, 100 lbs.‡‡ sulph. soda, 100 lbs. sulph. magnesia, and 3½ cwts. superphosphate	...	...	5646	6072	5586	5892	5718	6528	6816	5292	6576	7188	7728	14
15	1858–75, 18 years, 550 lbs. nitrate of soda; 1876–78, 300 lbs. sulph. potass, 100 lbs. sulph. soda, 100 lbs. sulph. magnesia, and 3½ cwts. superphosphate	...	...	3564	4116	4410	4452	4086	4116	4410	3150	4578	5286	3570	15
16	1858–78, 275 lbs. nitrate of soda, 300 lbs. sulph. potass, 100 lbs.‡‡ sulph. soda, 100 lbs. sulph. magnesia, and 3½ cwts. superphosphate	...	...	4236	4956	4812	5514	5178	5694	5964	4110	5754	5940	5736	16
17	1858–78, 275 lbs. nitrate of soda	...	...	2952	3588	3948	4092	4446	4014	4452	3204	4254	5082	3234	17
18	1865–78, mixture supplying the quantity of potass, soda, lime, magnesia, phosphoric acid, silica, and nitrogen contained in 1 ton of hay	...	...	...	...	...	...	...	...	...	2352	4684	4332	3074	18
19	1872–78, 275 lbs. nitrate of soda, 290 lbs. sulphate of potass, and 3½ cwts. superphosphate (equal in nitrogen and potass to plot 20)	...	...	...	...	...	...	...	...	...	...	...	...	...	19
20	1872–78, 327 lbs. nitrate of potass and 3½ cwts. superphosphate (equal in nitrogen and potass to plot 19)	...	...	...	...	...	...	...	...	...	...	...	...	...	20

* "Ammonia-salts" in all cases, equal parts sulphate and muriate of ammonia of commerce.

† "Superphosphate of lime" in all cases made from 200 lbs. bone ash, 150 lbs. sulphuric acid, sp. gr. 1·7 (and water).

‡ Plots 6, 8, and 10 had, besides the manures specified, 2000 lbs. sawdust per acre per annum for the first 7 years, 1856–62, but without effect.

§ 200 lbs., 1856–63 inclusive.

‖ 500 lbs., 1862 and 1863.

¶ Only 400 lbs. in 1859–60–61.

** The application of silicates did not commence until 1862; 9 years (1862–1870), 200 lbs. silicate of lime, and 200 lbs. silicate of soda; 1871 and since, 400 lbs. silicate of soda.

†† 550 lbs. nitrate of soda is reckoned to contain the same amount of nitrogen as 400 lbs. "ammonia-salts."

‡‡ 200 lbs., 1858-63 inclusive.

of manures applied per acre, on each plot, in each year, and the amount of hay per acre, removed 23 years, 1856–1878, inclusive.

Plots.	Produce of hay per acre, first crops only, first 20 years, 1856–1875 (continued).											Subsequent years.										Plots.
	Each year (continued).							Averages.				1875.			1876.	1877.			1878.			
	1869.	1870.	1871.	1872.	1873.	1874.	1875.	First period.	Second period.	Total period.	Duration of periods.	First crop.	Second crop.	Total.	One crop only.	First crop.	Second crop.	Total.	First crop.	Second crop.	Total.	
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1	6832	1828	4904	3531	3332	2628	3764	5538	4348	4824	8, 12, and 20 years .	3764	1960	5724	3320	4732	2248	6980	3448	1960	5408	1
2	6188	1556	3800	2831	2112	1816	2988	4804	3682	4131	8, 12, and 20 years .	2988	1320	4308	2288	3612	1824	5436	2340	1776	4116	2
3	4256	644	2844	1644	1372	1412	2236	2531	2236	2383	10, 10, and 20 years .	2236	1384	3620	1384	2364	1960	4324	1848	1496	3344	3
4–1	4508	812	2788	1772	1516	1472	2344	2732	2384	2527	7, 10, and 17 years .	2344	1728	4072	1860	3092	2100	5192	2184	1704	3888	4–1
4–2	5096	924	4284	3195	2912	2140	4100	4440	3414	3837	7, 10, and 17 years .	4100	1612	5712	3760	4696	1500	6196	3648	2408	6056	4–2
5	3990	628	3320	2514	1894	756	2696	3420	2471	2946	10, 10, and 20 years .	2696	2024	4720	1982	2952	2240	5192	1915	2104	4019	5
6	6328	1820	4206	2822	2918	2414	4008	3425	3502	3452	13, 7, and 20 years .	4008	1678	5686	3590	4222	2196	6418	4140	2114	6254	6
7	6124	1968	4414	4236	3892	3088	4560	3797	4118	3958	10, 10, and 20 years .	4560	2684	7244	3886	5100	2674	7774	3926	2532	6458	7
8	5194	1428	3366	2568	2058	1936	3182	4027	3098	3377	6, 14, and 20 years .	3182	1788	4970	2702	3624	1748	5372	2544	1932	4476	8
9	7700	3306	6576	5658	4894	3290	5828	6002	5421	5711	10, 10, and 20 years .	5828	2729	8557	5604	6054	2448	8502	6290	2707	8997	9
10	6412	2376	5218	4328	3700	2582	4806	6222	4725	5674	6, 14, and 20 years .	4806	2713	7519	4484	4880	2806	7686	4600	2456	7056	10
11–1	8428	4748	6348	7131	5236	2628	5224	6913	6006	6459	10, 10, and 20 years .	5224	5684	10908	6452	6796	5420	12216	5808	4604	10412	11–1
11–2	8792	5552	7364	7155	6328	4452	6728	7077	6909	6993	10, 10, and 20 years .	6728	4580	11308	7264	8500	3844	12344	6712	4248	10960	11–2
12	4352	1260	2960	2252	1804	1642	2632	2808	2564	2686	10, 10, and 20 years .	2632	1600	4232	1599	2165	2818	4983	1832	1784	3616	12
13	8694	5380	7066	7010	6384	5200	7286	6185	6678	6432	10, 10, and 20 years .	7286	3406	10692	7418	6276	3234	9510	6172	3302	9474	13
14	8526	6300	6930	6215	5796	5484	7026	5944	6777	6406	8, 10, and 18 years .	7026	1974	9000	7206	6258	2124	8382	5382	1692	7074	14
15	5976	1746	4326	3659	3780	2928	3276	4038	3913	3968	8, 10, and 18 years .	3276	1464	4740	3420	3784	2022	5806	2814	2394	5208	15
16	8316	3714	6384	4475	4662	3294	5040	5058	5332	5210	8, 10, and 18 years .	5040	1866	6906	4656	6096	2304	8400	4788	2292	7080	16
17	6090	2166	4308	3323	3192	2544	3360	3837	3755	3791	8, 10, and 18 years .	3360	1452	4812	2880	3738	1788	5526	3084	1590	4674	17
18	6230	1640	4250	3740	2932	2512	3900	3908	3301	3604	5½, 5½, and 11 years .	3900	1722	5622	3544	4500	2224	6724	3864	1936	5800	18
19	...	...	...	4488	4328	3840	4616	...	...	4318	4 years	4616	2256	6872	4152	4728	2152	6880	4425	1928	6353	19
20	...	...	...	4312	4032	3280	4744	...	...	4092	4 years	4744	2368	7112	4248	5144	1856	7000	4774	1576	6350	20

APPENDIX-TABLE II.—Estimated amounts per acre, of second crops, reckoned as Hay.

	Plot 1. Farm-yard manure first 8 years; am-monia-salts every year.	Plot 2. Farm-yard manure first 8 years; after-wards unma-nured.	Plot 3. Unma-nured continu-ously.	Plot 4–1. Super-phos-phate of lime alone; 1859 and since.	Plot 4–2. Super-phos-phate and am-monia-salts; 1859 and since.	Plot 5. Am-monia-salts alone.	Plot 6. Am-monia-salts first 13 years; after-wards mixed mineral manure.	Plot 7. Mixed mineral manure (with potass) every year.	Plot 8. Mixed mineral manure with potass 6 years; without after-wards.	Plot 9 as plot 7 and 400 lbs. am-monia-salts.	Plot 10 as plot 8 and 400 lbs. am-monia-salts.	Plot 11-1 as plot 7 and 800 lbs.* am-monia-salts.	Plot 11-2 as plot 11-1 with silicates in addi-tion; 1862 and since.	Plot 12. Unma-nured continu-ously.	Plot 13 as plot 9 and 2000 lbs. cut wheat straw.	Plot 14 as plot 7 and 550 lbs. nitrate soda.	Plot 15. 550 lbs. nitrate soda 18 years; mixed mineral manure after-wards.	Plot 16 as plot 7 and 275 lbs. nitrate soda.	Plot 17. 275 lbs. nitrate soda every year.	Plot 18. Mineral consti-tuents and nitrogen of 1 ton hay.	Plot 19. Super-phos-phate, nitrate soda, and sulphate potass.	Plot 20. Super-phos-phate and nitrate potass.
20 Years, 1856–1875 inclusive.																					
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1856	1188	1188	1188	(1188)	(1188)	1280	1280	1280	1280	1507	1507	2013		1558	2330	..	..	..	..	..	..	..
1857	1427	1427	950	(950)	(950)	1187	1187	1485	1485	1645	1645	2195		1189	1782	..	..	..	..	..	..	..
1858	1210	1210	1098	(877)	(877)	1098	1098	1373	1373	1645	1645	2195		1043	1645	1645	1645	1645	1645	..	..	..
1859	1098	1098	914	822	987	906	906	1234	1234	1234	1234	1646		822	1234	960	960	822	822	..	..	..
1860	2432	2432	2112	2112	2323	2222	2222	2378	2378	2434	2434	2434		2146	2496	2010	1507	1576	1507	..	..	..
1861	1755	1755	1426	1536	1646	1664	1664	1782	1782	1902	1902	2021		1664	2021	1728	1426	1701	1426	..	..	..
1862	2395	2395	1718	1883	2157	1846	1846	1901	1901	1883	2085	2725	2725	1755	2725	2304	2304	2304	2304	..	..	..
1863	1317	1152	822	1152	987	1098	1098	1206	1206	1082	1006	1462	1462	1098	1462	603	549	603	603	..	..	..
1864	771	771	549	549	731	869	869	693	869	869	434	869	869	560	640	1029	771	1029	771	..	..	..
1865	2011	2011	1462	2011	1371	1371	1371	1600	1600	1234	1234	2742	2742	1462	2286	1603	1166	1603	1603	..	..	..
1866	Second	crops	cut and	spread	on the	respec	tive pl	ots.														
1867	1317	1317	1098	1098	1317	1206	1206	1645	1645	1645	1645	2194	2194	1098	1645	768	1371	1371	1371	1115	..	..
1868	640	480	460	768	768	640	640	1024	1024	1024	1024	1280	1280	640	1280	1029	411	1029	1029	1029	..	..
1869	960	914	1098	1280	1280	1262	1590	1462	1462	1280	1280	1472	1472	778	1420	1115	864	1152	1098	1280	..	..
1870	Second	crops	cut and	spread	on the	respec	tive pl	ots.														..
1871	1859	1371	1646	1714	2742	1376	1792	1886	1646	1920	2286	2400	2400	2171	1772	3291	2058	3072	2987	2304	..	..
1872	1578	1462	2011	1576	2194	1166	1646	1920	1782	1874	1766	2149	2149	1954	2286	1371	1646	1782	1920	1800	2194	1578
1873	Second	and th	ird cro	ps cut	and sp	read on	the res	pective	plots.													
1874	Second	and th	ird cro	ps cut	and sp	read on	the res	pective	plots.													
1875†	1960	1320	1384	1728	1612	2024	1678	2684	1788	2729	2713	5684	4580	1600	3406	1974	1464	1866	1452	1722	2256	2368
Averages.																						
8 years 1856–63.	1603	1582	1279	1501‡	1620‡	1413	1413	1580	1580	1667	1682	2086	2086	1409	1984	1542‖	1399‖	1442‖	1385‖	..	..	..
8 years, 1864–5–7–8–9–71–2–5.	1387	1206	1213	1341	1502	1239	1349	1614	1477	1572	1548	2349	2211	1283	1842	1522	1219	1613	1529	..	..	..
16 years, 1856–65–7–8–9–71–2–5.	1495	1394	1246	1402§	1547§	1326	1381	1597	1528	1619	1615	2218	2149	1346	1913	1531¶	1296¶	1540¶	1467¶	..	..	..
Subsequent Years.																						
1876	Second	crops	cut and	spread	on the	respec	tive pl	ots.														
1877†	2248	1824	1960	2100	1500	2240	2196	2674	1748	2448	2806	5420	3844	2818	3234	2124	2022	2304	1788	2224	2152	1856
1878†	1960	1776	1496	1704	2408	2104	2114	2532	1932	2707	2456	4604	4248	1784	3302	1692	2394	2292	1590	1936	1928	1576

* 400 lbs. only in 1859, 1860, and 1861.
‡ Averages of 5 years only, 1859–63.
‖ Averages of 6 years only, 1858–63.
† Second crops cut, removed, and weighed.
§ Averages of 13 years only, 1859–65, and '67, '68, '69, '71, '72, and '75.
¶ Averages of 14 years only, 1858–65, and '67, '68, '69, '71, '72, and '75.

APPENDIX-TABLE III.—Actual amounts of Hay per acre (first crops), each year, on five selected plots; and the indices of those amounts.

Years.	Actual produce per acre (first crops); lbs.						Indices of actual amounts; highest any year = 1.						Years.
	Plot 3. Unmanured continuously.	Plot 7. Mixed mineral manure alone.	Plot 9. Mixed mineral manure and 400 lbs. ammonia-salts.	Plot 11. Mixed mineral manure and 800 lbs.* ammonia-salts.	Plot 14. Mixed mineral manure and 550 lbs. nitrate soda.	Means of plots 7, 9, and 11.	Plot 3. Unmanured continuously.	Plot 7. Mixed mineral manure alone.	Plot 9. Mixed mineral manure, and 400 lbs. ammonia-salts.	Plot 11. Mixed mineral manure, and 800 lbs.* ammonia-salts.	Plot 14. Mixed mineral manure and 550 lbs. nitrate soda.	Of mean produce of plots 7, 9, and 11.	
	20 YEARS, 1856–1875 INCLUSIVE.												
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.							
1856	2515	3429	6363	6970	..	5587	11	16	7	10	..	13	1856
1857	2856	3666	6422	6940	..	5676	4	15	5	11	..	11	1857
1858	2472	4082	7172	7508	5646	6254	12	11	2	5	15	2	1858
1859	2540	3416	6198	7150	6072	5588	10	17	9	7	11	12	1859
1860	2760	3928	5624	5744	5586	5099	7	12	14	18	16	16	1860
1861	2844	4488	6316	6710	5892	5838	5	3	8	13	12	7	1861
1862	3052	4424	6402	7114	5718	5980	3	5	6	9	14	5	1862
1863	2284	3870	6026	8364	6528	6087	13	14	10	2	8	4	1863
1864	2688	4130	5628	7426	6816	5728	8	10	13	6	6	9	1864
1865	1296	2540	3866	6024	5292	4143	19	19	18	14	18	18	1865
1866	2660	4180	4956	8092	6576	5743	9	9	16	3	7	8	1866
1867	3332	4458	5382	5808	7188	5216	2	4	15	16	3	15	1867
1868	1960	4264	6622	7616	7728	6167	15	7	3	4	2	3	1868
1869	4256	6124	7700	8610	8526	7478	1	1	1	1	1	1	1869
1870	644	1968	3306	5150	6300	3475	20	20	19	19	9	19	1870
1871	2844	4414	6576	6856	6930	5949	5	6	4	12	5	6	1871
1872	1644	4236	5658	7143	6215	5679	16	8	12	8	10	10	1872
1873	1372	3892	4894	5782	5796	4856	18	13	17	17	13	17	1873
1874	1412	3088	3290	3540	5484	3306	17	18	20	20	17	20	1874
1875	2236	4560	5828	5976	7026	5455	14	2	11	15	4	14	1875
Means	2383	3958	5711	6726	6407†	5465							Means
	SUBSEQUENT YEARS.												
1876	1384	3886	5604	6858	7206	5449							1876
1877	2364	5100	6054	7648	6258	6267							1877
1878	1848	3926	6290	6260	5382	5492							1878

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

† Averages of 18 years only, 1858–1875.

Appendix-Table IV.—Rainfall at Rothamsted.—Inches.

Years.	Monthly.												Totals.						Years.
	July.	August.	Sept.	October.	Nov.	Dec.	Jan.	Feb.	March.	April.	May.	June.	12 months, July to June, inclusive.	4 months, July, August, September, October.	4 months, November, December, January, February.	4 months, March, April, May, June.	3 months, April, May, June.	2 months, April and May.	
20 Years, 1855–56 to 1874–75.																			
	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	
1855–6	6·96	2·63	1·54	5·50	2·47	1·72	2·78	1·35	1·00	2·61	4·71	1·91	35·18	16·63	8·32	10·23	9·23	7·32	1855–6
1856–7	1·48	2·65	2·19	2·87	1·42	2·24	3·71	0·57	1·48	2·16	1·11	2·21	24·09	9·19	7·94	6·96	5·48	3·27	1856–7
1857–8	1·61	3·08	4·17	5·91	2·25	0·58	0·97	1·43	0·80	2·58	2·55	0·96	26·89	14·77	5·23	6·89	6·09	5·13	1857–8
1858–9	3·19	1·56	1·54	1·60	0·88	1·99	1·34	2·01	1·73	2·70	2·13	3·41	24·08	7·89	6·22	9·97	8·24	4·83	1858–9
1859–60	3·02	2·78	3·44	2·86	2·28	2·79	3·42	1·22	2·03	1·94	4·30	6·26	36·34	12·10	9·71	14·53	12·50	6·24	1859–60
1860–1	2·03	4·22	2·77	1·77	2·45	1·43	0·81	2·41	2·29	1·28	1·04	2·98	25·48	10·79	7·10	7·59	5·30	2·32	1860–1
1861–2	3·19	0·89	1·63	1·46	3·99	1·58	1·77	0·60	3·06	2·84	2·91	3·41	27·33	7·17	7·94	12·22	9·16	5·75	1861–2
1862–3	1·80	2·50	2·29	4·05	1·34	1·74	4·04	0·74	0·91	0·96	1·01	4·60	25·98	10·64	7·86	7·48	6·57	1·97	1862–3
1863–4	0·70	2·87	2·91	2·35	2·22	1·64	1·28	0·77	2·47	1·25	1·88	1·79	22·13	8·83	5·91	7·39	4·92	3·13	1863–4
1864–5	0·89	0·78	3·14	1·29	2·47	0·55	4·01	1·84	1·42	0·47	3·05	0·68	20·59	6·10	8·87	5·62	4·20	3·52	1864–5
1865–6	2·93	5·17	0·17	7·36	2·66	1·46	3·97	3·24	1·65	1·95	1·24	4·51	36·31	15·63	11·33	9·35	7·70	3·19	1865–6
1866–7	3·01	3·44	4·10	1·82	2·16	2·70	2·56	1·94	2·17	2·82	3·35	1·06	31·13	12·37	9·36	9·40	7·23	6·17	1866–7
1867–8	4·10	2·15	2·06	1·86	0·32	2·04	3·93	1·49	1·92	2·19	0·73	0·37	23·16	10·17	7·78	5·21	3·29	2·92	1867–8
1868–9	0·37	3·77	2·80	2·04	0·42	4·55	3·44	2·41	1·48	2·13	3·23	1·07	27·71	8·98	10·82	7·91	6·43	5·36	1868–9
1869–70	0·97	1·35	2·79	2·05	2·38	3·20	1·81	2·10	1·80	0·46	1·35	0·98	21·24	7·16	9·49	4·59	2·79	1·81	1869–70
1870–1	1·12	1·59	2·30	4·13	1·40	2·65	1·45	1·63	1·50	2·88	0·96	3·86	25·47	9·14	7·13	9·20	7·70	3·84	1870–1
1871–2	4·00	0·77	4·07	1·79	0·66	1·42	4·68	1·47	2·15	1·63	2·89	3·09	28·62	10·63	8·23	9·76	7·61	4·52	1871–2
1872–3	2·89	2·29	1·36	4·67	3·87	4·04	4·02	1·34	2·05	0·63	1·66	1·75	30·57	11·21	13·27	6·09	4·04	2·29	1872–3
1873–4	2·54	2·69	2·38	2·83	1·99	0·71	1·93	1·73	0·65	2·14	1·19	1·59	22·37	10·44	6·36	5·57	4·92	3·33	1873–4
1874–5	2·81	1·75	3·62	3·23	2·35	1·80	3·99	1·18	0·87	1·56	2·74	3·53	29·43	11·41	9·32	8·70	7·83	4·30	1874–5
Means	2·46	2·49	2·51	3·07	1·99	2·04	2·79	1·57	1·67	1·86	2·20	2·50	27·21	10·53	8·39	8·23	6·56	4·06	Means
Subsequent Years.																			
1875–6	5·66	1·10	2·80	5·90	4·43	1·19	1·81	3·05	2·90	3·33	0·78	1·35	34·30	15·46	10·48	8·36	5·46	4·11	1875–6
1876–7	1·46	2·98	5·02	1·52	4·20	6·00	4·99	2·10	2·55	2·76	2·82	1·43	37·83	10·98	17·29	9·56	7·01	5·58	1876–7
1877–8	3·28	2·60	1·53	1·95	5·16	2·28	1·75	1·80	0·98	4·09	4·98	2·51	32·91	9·36	10·99	12·56	11·58	9·07	1877–8

APPENDIX-TABLE V.—Rainfall at Rothamsted.—Number of days when 0·01 inch, or more, fell.

Years.	Monthly. July.	August.	Sept.	October.	Nov.	Dec.	Jan.	Feb.	March.	April.	May.	June.	Totals. 12 months, July to June, inclusive.	4 months, July, August, September, October.	4 months, November, December, January, February.	4 months, March, April, May, June.	3 months, April, May, June.	2 months, April and May.	Years.
20 YEARS, 1855–56 TO 1874–75.																			
1855-6	14	9	9	20	15	12	18	10	5	13	20	6	151	52	55	44	39	33	1855-6
1856-7	14	12	10	14	11	17	21	10	12	15	10	11	157	50	59	48	36	25	1856-7
1857-8	9	10	18	12	14	9	7	6	5	11	16	7	124	49	36	39	34	27	1857-8
1858-9	16	11	12	11	14	19	13	14	9	15	9	13	156	50	60	46	37	24	1858-9
1859-60	8	12	13	14	10	16	20	8	13	12	13	29	168	47	54	67	54	25	1859-60
1860-1	13	21	15	13	13	11	8	20	21	5	7	15	162	62	52	48	27	12	1860-1
1861-2	21	11	14	13	20	14	16	7	18	14	18	16	182	59	57	66	48	32	1861-2
1862-3	13	11	11	23	18	16	17	9	12	9	9	16	164	58	60	46	34	18	1862-3
1863-4	6	17	16	20	16	13	12	14	14	6	8	15	157	59	55	43	29	14	1863-4
1864-5	6	8	16	7	15	3	18	10	11	6	17	5	122	37	46	39	28	23	1864-5
1865-6	17	14	6	18	17	7	20	18	10	11	9	14	161	55	62	44	34	20	1865-6
1866-7	12	18	24	11	12	15	12	11	12	18	15	10	170	65	50	55	43	33	1866-7
1867-8	17	9	7	17	9	10	13	11	13	10	6	4	126	50	43	33	20	16	1867-8
1868-9	4	15	9	11	8	22	14	16	16	12	16	8	151	39	60	52	36	28	1868-9
1869-70	6	11	12	17	12	18	17	21	15	8	10	5	152	46	68	38	23	18	1869-70
1870-1	12	8	10	23	14	8	12	12	12	14	8	16	149	53	46	50	38	22	1870-1
1871-2	18	5	13	10	12	13	21	16	10	13	18	15	164	46	62	56	46	31	1871-2
1872-3	16	14	14	21	21	23	16	7	18	9	13	10	182	65	67	50	32	22	1872-3
1873-4	10	19	12	22	19	12	18	16	14	10	11	13	176	63	65	48	34	21	1873-4
1874-5	13	16	17	20	14	13	24	10	10	9	10	15	171	66	61	44	34	19	1874-5
Means	12	13	13	16	14	14	16	12	13	11	12	12	157	54	56	48	35	24	Means
SUBSEQUENT YEARS.																			
1875-6	15	9	16	19	19	15	12	22	17	19	9	11	183	59	68	56	39	28	1875-6
1876-7	11	14	25	15	20	27	26	18	23	13	18	7	217	65	91	61	38	31	1876-7
1877-8	17	17	15	17	23	19	17	15	9	16	23	13	201	66	74	61	52	39	1877-8

APPENDIX-TABLE VI.—Mean maximum temperature, at Greenwich (Fahrenheit).

Years.	Monthly.												Averages.						Years.
	July.	August.	Sept.	October.	Nov.	Dec.	Jan.	Feb.	March.	April.	May.	June.	12 months, July to June, inclusive.	4 months, July, August, September, October.	4 months, November, December, January, February.	4 months, March, April, May, June.	3 months, April, May, June.	2 months, April and May.	
20 YEARS, 1855–56 TO 1874–75.																			
1855–6	73·3°	72·9°	68·5°	58·7°	46·5°	40·2°	43·7°	47·3°	45·7°	57·4°	59·1°	70·8°	57·0°	68·4°	44·4°	58·3°	62·4°	58·3°	1855–6
1856–7	73·3	75·9	65·5	59·8	47·1	45·1	41·8	47·2	50·5	55·8	67·1	75·9	58·8	68·6	45·3	62·3	66·3	61·5	1856–7
1857–8	77·8	78·1	70·2	61·6	51·9	50·3	43·8	41·8	50·7	57·6	63·7	79·5	61·0	72·1	47·9	63·0	66·9	60·7	1857–8
1858–9	73·8	75·6	70·9	59·9	46·1	45·1	45·5	50·4	54·2	56·9	64·9	73·9	59·8	70·1	46·8	62·5	65·2	60·9	1858–9
1859–60	81·8	76·1	67·1	59·0	49·4	41·5	45·0	42·5	49·2	53·7	65·5	65·0	58·0	71·0	44·6	58·4	61·4	59·6	1859–60
1860–1	69·2	67·2	63·4	58·6	46·7	40·5	39·6	48·2	52·7	55·0	63·5	70·8	56·3	64·6	43·8	60·5	63·1	59·3	1860–1
1861–2	72·3	75·6	68·3	64·1	47·3	45·9	43·9	46·5	50·0	57·5	66·4	67·1	58·7	70·1	45·9	60·3	63·7	62·0	1861–2
1862–3	70·8	71·0	67·6	60·5	45·8	48·0	46·9	49·5	53·7	61·2	64·4	70·1	59·1	67·5	47·6	62·4	65·2	62·8	1862–3
1863–4	74·3	73·8	63·5	58·8	51·1	48·6	41·4	41·5	49·8	58·3	64·8	69·5	58·0	67·6	46·1	60·9	64·2	61·6	1863–4
1864–5	75·3	72·8	67·3	58·2	48·5	42·5	40·9	42·2	44·0	66·3	67·9	73·6	58·3	68·4	43·5	63·0	69·3	67·1	1864–5
1865–6	75·7	70·9	76·4	60·0	50·8	46·7	47·8	47·1	48·4	58·2	61·4	73·2	59·7	70·8	48·1	60·3	64·3	59·8	1865–6
1866–7	72·6	69·4	65·1	58·2	50·5	47·6	39·5	50·7	44·5	58·7	64·7	70·2	57·6	66·3	47·1	59·5	64·5	61·7	1866–7
1867–8	71·1	73·3	68·0	57·2	47·8	42·2	41·4	49·9	52·9	58·8	70·5	76·3	59·1	67·4	45·4	64·6	68·5	64·7	1867–8
1868–9	82·0	75·1	71·7	56·9	46·9	50·5	46·0	51·8	44·8	61·6	60·7	67·4	59·6	71·4	48·8	58·6	63·2	61·2	1868–9
1869–70	77·0	72·3	68·6	57·5	49·1	42·0	42·6	41·4	46·9	62·0	66·9	74·8	58·4	68·9	43·8	62·7	67·9	64·5	1869–70
1870–1	78·1	72·6	66·3	58·2	47·8	38·0	37·4	48·3	55·0	57·8	64·4	66·3	57·6	68·9	42·9	60·9	62·8	61·1	1870–1
1871–2	72·6	78·1	67·5	58·6	43·2	42·2	46·3	51·7	53·5	59·3	62·1	71·3	58·9	69·2	45·9	61·6	64·2	60·7	1871–2
1872–3	78·2	72·9	68·2	56·7	50·8	47·0	46·8	39·2	51·3	57·4	62·3	70·2	58·4	69·0	46·0	60·3	63·3	59·9	1872–3
1873–4	76·6	74·7	65·2	57·0	50·1	45·6	47·3	45·0	52·8	61·5	63·2	71·1	59·2	68·4	47·0	62·2	65·3	62·4	1873–4
1874–5	79·0	72·1	68·4	59·5	48·4	37·9	47·8	40·4	47·1	57·3	64·7	69·4	57·7	69·8	43·6	59·6	63·8	61·0	1874–5
Means	75·2	73·5	67·9	59·0	48·3	44·4	43·8	46·1	49·9	58·6	64·4	71·3	58·9	68·9	45·7	61·1	64·8	61·5	Means
SUBSEQUENT YEARS.																			
1875–6	67·6	73·7	70·2	57·2	48·8	43·2	42·8	47·5	49·2	57·6	60·7	69·4	57·3	67·2	45·6	59·2	62·6	59·2	1875–6
1876–7	77·7	74·5	65·3	60·2	49·9	48·6	49·5	50·4	49·3	54·3	59·1	74·4	59·4	69·4	49·6	59·3	62·6	56·7	1876–7
1877–8	70·6	71·6	62·5	57·8	52·1	45·9	45·3	47·6	49·9	58·2	64·8	71·1	58·1	65·6	47·7	61·0	64·7	61·5	1877–8

Appendix-Table VII.—Mean minimum temperature, at Greenwich (Fahrenheit).

Years.	Monthly. July.	August.	Sept.	October.	Nov.	Dec.	Jan.	Feb.	March.	April.	May.	June.	Averages. 12 months, July to June, inclusive.	4 months, July, August, September, October.	4 months, November, December, January, February.	4 months, March, April, May, June.	3 months, April, May, June.	2 months, April and May.	Years.
20 Years, 1855–56 to 1874–75.																			
1855–6	54·1°	53·7°	47·7°	45·2°	36·8°	30·9°	35·2°	37·6	33·3°	38·3°	42·6°	50·0°	42·1°	50·2°	35·1°	41·1°	43·6°	40·5°	1855–6
1856–7	52·4	54·7	47·6	46·1	35·4	35·3	32·1	32·5	35·9	38·8	44·0	50·5	42·1	50·2	33·8	42·3	44·4	41·4	1856–7
1857–8	54·3	56·4	52·1	47·1	40·6	39·6	31·7	29·8	33·6	38·0	42·7	53·9	43·3	52·5	35·4	42·1	44·9	40·4	1857–8
1858–9	51·8	52·1	52·6	43·9	33·6	36·6	35·5	36·3	40·5	39·1	43·9	53·0	43·2	50·1	35·5	44·1	45·3	41·5	1858–9
1859–60	57·2	54·3	49·0	45·0	35·5	31·8	34·8	30·1	35·0	35·6	44·6	48·5	41·8	51·4	33·1	40·9	42·9	40·1	1859–60
1860–1	50·1	51·8	45·8	44·5	35·3	31·9	28·7	36·9	37·1	36·0	43·0	51·3	41·0	48·1	33·2	41·9	43·4	39·5	1860–1
1861–2	53·4	53·8	48·2	47·7	34·1	36·0	34·3	36·7	38·4	41·7	47·9	49·3	43·5	50·8	35·3	44·3	46·3	44·8	1861–2
1862–3	50·8	51·4	50·1	45·6	34·3	38·6	36·6	35·7	35·6	40·1	42·7	50·1	42·6	49·5	36·3	42·1	44·3	41·4	1862–3
1863–4	49·4	53·7	45·8	46·1	40·3	36·8	31·7	31·2	34·3	40·0	44·9	49·1	41·9	48·8	35·0	42·1	44·7	42·5	1863–4
1864–5	51·2	48·5	49·1	44·1	35·5	33·7	31·8	32·2	31·1	41·5	46·3	49·9	41·2	48·2	33·3	42·2	45·9	43·9	1864–5
1865–6	54·3	51·5	53·6	43·7	38·7	38·1	36·7	34·7	34·5	40·8	40·8	52·0	43·3	50·3	37·1	42·0	44·5	40·8	1865–6
1866–7	52·5	52·3	50·6	45·7	38·0	37·4	28·5	39·5	33·0	42·3	44·7	49·1	42·8	50·3	35·9	42·3	45·4	43·5	1866–7
1867–8	50·8	53·4	50·3	42·0	35·3	32·1	32·8	36·8	36·8	40·1	46·1	50·8	42·3	49·1	34·3	43·5	45·7	43·1	1857–8
1868–9	55·7	55·0	51·1	40·2	36·1	41·1	36·5	39·7	32·3	41·8	43·7	46·0	43·3	50·5	38·4	41·0	43·8	42·8	1868–9
1869–70	54·5	52·4	52·4	42·0	37·4	33·4	34·0	31·9	34·0	38·4	42·0	50·7	41·9	50·3	34·2	41·3	43·7	40·2	1869–70
1870–1	56·0	53·1	46·4	42·8	35·4	28·9	29·3	37·5	36·7	41·2	42·1	47·9	41·4	49·6	32·8	42·0	43·7	41·7	1870–1
1871–2	54·0	53·8	50·3	41·9	32·7	34·2	37·0	39·2	37·7	40·1	42·5	50·0	42·8	50·0	35·8	42·6	44·2	41·3	1871–2
1872–3	54·8	52·5	49·1	41·1	40·8	38·7	38·0	30·8	35·2	37·9	42·5	51·0	42·7	49·4	37·1	41·7	43·8	40·2	1872–3
1873–4	53·9	54·4	46·1	40·6	38·8	35·2	36·2	33·5	36·6	41·3	40·7	48·3	42·1	48·8	35·9	41·7	43·4	41·0	1873–4
1874–5	53·6	51·5	50·3	45·7	39·6	28·6	39·6	31·8	36·0	39·4	50·0	51·8	43·2	50·3	34·9	44·3	47·1	44·7	1874–5
Means	53·2	53·0	49·4	44·1	36·7	35·0	34·0	34·7	35·4	39·6	43·9	50·2	42·4	50·0	35·1	42·3	44·6	41·8	Means
Subsequent Years.																			
1875–6	53·2	55·3	53·0	42·4	37·2	34·1	32·0	36·1	34·6	40·2	40·2	49·5	42·3	51·0	34·9	41·1	43·3	40·2	1875–6
1876–7	56·1	54·2	48·9	46·9	38·3	39·5	36·8	38·0	34·1	39·5	41·1	51·5	43·7	51·5	38·4	41·6	44·0	40·3	1876–7
1877–8	53·4	55·8	46·4	41·4	39·7	35·9	35·7	37·3	36·4	39·6	47·5	51·4	43·4	49·3	37·1	43·7	46·1	43·6	1877–8

APPENDIX-TABLE VIII.—Mean temperature, at Greenwich (Fahrenheit).

Years.	Monthly.												Averages.						Years.
	July.	August.	Sept.	October.	Nov.	Dec.	Jan.	Feb.	March.	April.	May.	June.	12 months, July to June, inclusive.	4 months, July, August, September, October.	4 months, November, December, January, February.	4 months, March, April, May, June.	3 months, April, May, June.	2 months, April and May.	
20 Years, 1855–56 to 1874–75.																			
1855–6	62·1	62·1	57·1	51·2	41·3	35·6	39·4	42·0	38·7	46·8	49·5	55·2	48·4	58·1	39·6	47·6	50·5	48·2	1855–6
1856–7	61·1	63·6	55·2	51·7	40·7	40·2	36·6	39·2	41·8	45·7	54·0	61·8	49·3	57·9	39·2	50·8	53·8	49·9	1856–7
1857–8	64·5	65·8	59·7	52·9	45·8	45·1	37·5	34·6	41·4	46·2	51·7	64·9	50·7	60·7	40·8	51·1	54·3	49·0	1857–8
1858–9	60·6	62·0	60·3	50·8	39·6	41·0	40·4	43·1	46·4	46·6	53·1	61·4	50·4	58·4	41·0	51·9	53·7	49·9	1858–9
1859–60	68·1	63·5	56·7	50·9	41·9	36·8	39·7	35·7	41·1	42·9	53·8	54·8	48·8	59·8	38·5	48·2	50·5	48·4	1859–60
1860–1	57·6	57·7	53·4	50·6	40·8	36·3	33·9	42·1	43·8	44·3	51·9	59·1	47·6	54·8	38·3	49·8	51·8	48·1	1860–1
1861–2	60·9	63·2	57·1	54·9	40·8	41·0	39·0	41·1	43·1	48·4	55·4	56·3	50·1	59·0	40·5	50·8	53·3	51·9	1861–2
1862–3	59·1	59·5	57·7	51·8	39·8	43·6	41·8	42·1	43·9	49·1	52·0	58·1	49·9	57·0	41·8	50·8	53·1	50·5	1862–3
1863–4	60·8	61·9	53·7	51·6	45·7	43·2	36·5	36·0	41·3	48·2	53·8	57·4	49·2	57·0	40·4	50·2	53·1	51·0	1863–4
1864–5	61·8	59·6	56·9	50·5	42·0	38·5	36·3	36·6	36·6	52·3	56·1	60·2	49·0	57·2	38·4	51·3	56·2	54·2	1864–5
1865–6	63·8	59·9	63·9	50·9	44·8	42·4	42·6	40·5	40·5	47·9	50·1	60·9	50·7	59·6	42·6	49·9	53·0	49·0	1865–6
1866–7	61·0	59·4	56·4	51·3	44·3	42·9	34·2	44·7	37·7	49·0	53·4	58·1	49·4	57·0	41·5	49·6	53·5	51·2	1866–7
1867–8	59·4	62·0	57·6	48·7	41·1	37·5	37·2	43·0	44·0	48·1	57·3	62·0	49·8	56·9	39·7	52·9	55·8	52·7	1867–8
1868–9	67·5	63·6	60·5	47·9	41·5	46·0	41·1	45·3	37·5	50·3	50·5	55·3	50·6	59·9	43·5	48·4	52·0	50·4	1868–9
1869–70	64·5	60·8	59·0	48·9	43·0	37·9	38·3	36·2	39·6	48·9	53·4	60·9	49·4	58·3	38·9	50·7	54·4	51·2	1869–70
1870–1	65·4	61·1	55·7	49·8	41·5	33·6	33·2	42·4	44·9	47·7	51·9	54·8	48·5	58·0	37·7	49·8	51·5	49·8	1870–1
1871–2	61·7	64·8	57·4	49·4	37·6	38·3	41·3	44·8	44·6	48·3	50·9	59·2	49·9	58·3	40·5	50·8	52·8	49·6	1871–2
1872–3	65·0	61·0	57·4	47·8	45·3	42·9	42·1	34·6	41·9	45·9	50·6	58·9	49·5	57·8	41·2	49·3	51·8	48·3	1872–3
1873–4	63·4	62·7	54·7	47·8	44·2	40·6	41·7	38·7	43·7	50·0	50·5	58·0	49·7	57·2	41·3	50·6	52·8	50·3	1873–4
1874–5	64·4	60·1	57·9	51·7	42·0	33·2	43·8	35·5	40·7	46·8	55·3	59·0	49·2	58·5	38·6	50·5	53·7	51·1	1874–5
Means.	62·6	61·7	57·4	50·6	42·2	39·8	38·8	39·8	41·7	47·7	52·8	58·8	49·5	58·1	40·2	50·3	53·1	50·3	Means.
Subsequent Years.																			
1875–6	58·7	62·6	60·0	49·0	42·5	39·0	37·4	41·5	41·2	47·5	49·1	58·0	48·9	57·6	40·1	49·0	51·5	48·3	1875–6
1876–7	65·0	62·9	55·8	52·7	44·0	44·3	43·1	44·0	40·8	45·6	48·7	61·4	50·7	59·1	43·9	49·1	51·9	47·2	1876–7
1877–8	60·6	62·1	53·3	49·2	46·0	41·3	40·6	42·4	42·4	47·6	54·5	59·4	50·0	56·3	42·6	51·0	53·8	51·1	1877–8

APPENDIX-TABLE IX.—Mean range of temperature, at Greenwich (Fahrenheit).

Years.	Monthly.												Averages.						Years.
	July.	August.	Sept.	October.	Nov.	Dec.	Jan.	Feb.	March.	April.	May.	June.	12 months, July to June, inclusive.	4 months, July, August, September, October.	4 months, November, December, January, February.	4 months, March, April, May, June.	3 months, April, May, June.	2 months, April and May.	
20 YEARS, 1855–56 TO 1874–75.																			
1855–6	19·2°	19·2°	20·8°	13·5°	9·7°	9·3°	8·5°	9·7°	12·4°	19·1°	16·5°	20·8°	14·9°	18·2°	9·3°	17·2°	18·8°	17·8°	1855–6
1856–7	20·9	21·2	17·9	13·7	11·7	9·8	9·7	14·7	14·6	17·0	23·1	24·4	16·6	18·4	11·5	19·8	21·5	20·1	1856–7
1857–8	23·5	21·7	18·1	14·5	11·3	10·7	11·9	12·0	17·1	19·6	21·0	25·6	17·3	19·5	11·5	20·8	22·1	20·3	1857–8
1858–9	22·0	23·5	18·3	16·0	12·5	8·5	10·0	14·1	13·7	17·8	21·0	20·9	16·5	20·0	11·3	18·3	19·9	19·4	1858–9
1859–60	24·6	21·8	18·1	14·0	13·9	9·7	10·2	12·4	14·2	18·1	20·9	16·5	16·2	19·6	11·6	17·4	18·5	19·5	1859–60
1860–1	19·1	15·4	17·6	14·1	11·4	8·6	10·9	11·3	15·6	19·0	20·5	19·5	15·3	16·6	10·5	18·6	19·7	19·8	1860–1
1861–2	18·9	21·8	20·1	16·4	13·2	9·9	9·6	9·8	11·6	15·8	18·5	17·8	15·3	19·3	10·6	15·9	17·4	17·1	1861–2
1862–3	20·0	19·6	17·5	14·9	11·5	9·4	10·3	13·8	18·1	21·1	21·7	20·0	16·5	18·0	11·3	20·2	20·9	21·4	1862–3
1863–4	24·9	20·1	17·7	12·7	10·8	11·8	9·7	10·3	15·5	18·3	19·9	20·4	16·0	18·9	10·7	18·5	19·5	19·1	1863–4
1864–5	24·1	24·3	18·2	14·1	13·0	8·8	9·1	10·0	12·9	24·8	21·6	23·7	17·1	20·2	10·2	20·8	23·4	23·2	1864–5
1865–6	21·4	19·4	22·8	16·3	12·1	8·6	11·1	12·4	13·9	17·4	20·6	21·2	16·4	20·0	11·0	18·3	19·7	19·0	1865–6
1866–7	20·1	17·1	14·5	12·5	12·5	10·2	11·0	11·2	11·5	16·4	20·0	21·1	14·8	16·0	11·2	17·3	19·2	18·2	1866–7
1867–8	20·3	19·9	17·7	15·2	12·5	10·1	8·6	13·1	16·1	18·7	24·4	25·5	16·8	18·3	11·1	21·2	22·9	21·5	1867–8
1868–9	26·3	20·1	20·6	16·7	10·8	9·4	9·5	12·1	12·5	19·8	17·0	21·4	16·4	20·9	10·5	17·7	19·4	18·4	1868–9
1869–70	22·5	19·9	16·2	15·5	11·7	8·6	8·6	9·5	12·9	23·6	24·9	24·1	16·5	18·5	9·6	21·4	24·2	24·2	1869–70
1870–1	22·1	19·5	20·4	15·4	12·4	9·1	8·1	10·8	18·2	16·6	22·3	18·4	16·1	19·4	10·1	18·9	19·1	19·4	1870–1
1871–2	18·6	24·3	17·2	16·7	10·4	8·0	9·2	12·5	15·7	19·2	19·7	21·3	16·1	19·2	10·0	19·0	20·1	19·4	1871–2
1872–3	23·4	20·4	19·1	15·6	10·0	8·3	8·8	8·4	16·1	19·5	19·8	19·2	15·7	19·6	8·9	18·6	19·5	19·7	1872–3
1873–4	22·7	20·3	19·1	16·4	11·3	10·4	11·1	11·5	16·2	20·2	22·5	22·8	17·0	19·6	11·1	20·4	21·8	21·3	1873–4
1874–5	25·4	20·6	18·1	14·4	12·8	12·0	8·2	8·6	11·1	17·9	14·7	17·6	15·1	19·6	10·4	15·3	16·7	16·3	1874–5
Means	22·0	20·5	18·5	14·9	11·8	9·6	9·6	11·4	14·6	19·1	20·5	21·1	16·2	19·0	10·6	18·8	20·2	19·8	Means
SUBSEQUENT YEARS.																			
1875–6	14·4	18·4	17·2	14·8	11·6	9·1	10·8	11·4	14·6	17·4	20·5	19·9	15·0	16·2	10·7	18·1	19·3	19·0	1875–6
1876–7	21·6	20·3	16·4	13·3	11·6	9·1	12·7	12·4	15·2	14·8	18·0	22·9	15·7	17·9	11·5	17·7	18·6	16·4	1876–7
1877–8	17·2	15·8	16·1	16·4	12·4	10·0	9·6	10·3	13·5	18·6	17·3	19·7	14·7	16·4	10·6	17·3	18·5	18·0	1877–8

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