XXIX.—*Further Report of Experiments with different Manures on Permanent Meadow Land.* By J. B. Lawes, F.R.S., F.C.S., and J. H. Gilbert, Ph.D., F.R.S., F.C.S.

The object of the present Report is to give an account of the produce of hay per acre, the chemical composition of the hay, and the amount of certain constituents removed from the land, in the fourth, fifth, sixth, and seventh seasons of experiments on the application of different descriptions of manure, each applied (with some few exceptions or modifications) year after year on the same of a series of plots of permanent meadow land. The results obtained on the above points in the first, second, and third years, and on the variation in the description of plants developed in the third year, were given in vols. xix. and xx. of this Journal; and in the last Number (vol. xxiv., part 1) a detailed account of the description of plants developed by the different manures in the last or seventh season (1862), was given.

It is proposed to give the numerical results obtained during the last four years in regard to the points in question in some detail, but to comment on them much more briefly than it was found desirable to do when treating of the subject for the first time, in the Report above alluded to, to which we would refer the reader for a more detailed consideration of some of the points now discussed more briefly. We shall, however, give in the Tables a condensed summary of the results obtained over the whole seven years of the experiments, side by side with those of the later years, and in the course of our comments frequently compare the earlier and the later results.

The following is a detailed statement of the manuring of each plot; and, unless otherwise stated, it has been the same every year since the commencement of the experiments in 1856. The quantities per acre are given.

Plot 1. Unmanured.

Plot 2. Unmanured (duplicate plot at the further end of the series).

Plot 3*a*. Superphosphate of lime; composed of 200 lbs. of bone ash, and 150 lbs. sulphuric acid of sp. gr. 1·7. 4th season (commencing in 1859); sawdust alone the three previous years.

Plot 3*b*. Superphosphate of lime; and 400 lbs. ammonia-salts (equal parts sulphate and muriate of commerce, supplying about 82 lbs. nitrogen per acre). 4th season (commencing in 1859); the three previous seasons sawdust alone.

Plot 4. 400 lbs. ammonia-salts.

Plot 5. 400 lbs. ammonia-salts, and 2000 lbs. sawdust.

Plot 6. 275 lbs. nitrate of soda of commerce (containing about 41 lbs. nitrogen). 5th season (commencing 1858).

Plot 7. 550 lbs. nitrate of soda (containing about 82 lbs. nitrogen). 5th season (commencing in 1858).

Plot 8. Mixed mineral manure, composed of—
300 lbs. sulphate of potass.
200 lbs. sulphate of soda.
100 lbs. sulphate of magnesia.
Superphosphate of lime, as above.

Plot 9. Mixed mineral manure, and 2000 lbs. sawdust. (The mixed mineral manure as plot 8 to 1861 inclusive, and in 1862 the sulphate of potass excluded, and the amount of sulphate of soda raised to 500 lbs.).

Plot 10. Mixed mineral manure, as plot 8, and 400 lbs. ammonia-salts.

Plot 11. Mixed mineral manure, as plot 9, 400 lbs. ammonia-salts, and 2000 lbs. sawdust.

Plot 12. Mixed mineral manure, as plot 8, 400 lbs. ammonia-salts, and 2000 lbs. cut wheat-straw.

Plot 13*a*. Mixed mineral manure, as plot 8, and 800 lbs. ammonia-salts, equal about 164 lbs. nitrogen (only 400 lbs. ammonia-salts in 1859, 1860, and 1861).

Plot 13*b*. Mixed mineral manure, as plot 13*a*, to 1861 inclusive; the same, with 200 lbs. silicate of soda and 200 lbs. silicate of lime in addition, in 1862, and 800 lbs. ammonia-salts (only 400 lbs. ammonia-salts in 1859, 1860, and 1861).

Plot 14. Mixed mineral manure, as plot 8, and 275 lbs. nitrate of soda. 5th season (commencing in 1858).

Plot 15. Mixed mineral manure, as plot 8, and 550 lbs. nitrate of soda. 5th season (commencing in 1858).

Plot 16. 14 tons farmyard manure.

Plot 17. 14 tons farmyard manure, and 200 lbs. ammonia salts.

The first crop each year has always been mown for hay, and the after-grass eaten off by sheep, once or twice as might be required, a certain number, according to the amount of grass, being folded on each plot, and the number of days occupied in its consumption noted.

Produce of Hay per acre (First Crop).

In Table I. (p. 530) are given the quantities of hay obtained per acre (first crop) from each plot in each of the four years, 1859, 1860, 1861, and 1862; also the average annual produce, and average annual increase by manure, over the four and over the

whole seven years of the experiments (1856-1862 inclusive). It is, of course, a matter of much interest to consider, not only the actual amounts of produce, or of increase, obtained from each of the differently manured plots, but also, whether the amounts increase or diminish year by year as the experiments proceed.

The duplicate unmanured plot, which was somewhat shaded from the afternoon sun, gave each year rather more produce than the other. Taking the mean of the two, the average annual yield of hay per acre, without manure, was, over the whole seven years, nearly 25¼ cwts., and over the last four years rather more than 26 cwts., showing that there is as yet no indication of progressive deterioration where only the natural produce of the soil and season is taken from the land. Nor is there as yet evidence of material falling off in gross produce in any case where artificial mineral manures were employed, notwithstanding that none of those used supplied every mineral or inorganic * constituent taken off in the increased crop. The details

* The terms "mineral" or "inorganic," as applied to the constituents of manures or crops, are, for convenience, employed throughout this paper to designate the incombustible or "ash constituents," they having been generally employed in this restricted sense by Liebig and most other writers on agricultural chemistry during the last twenty years or more. Yet, in his recent work (Einleitung in die Naturgesetze des Feldbaues, p. 32 *et seq.*) Baron Liebig repudiates and ridicules such a classification as unscientific, claims ammonia and its salts as mineral manures, and accuses Mr. Lawes of setting up, in opposition to his own, a theory according to which mineral or inorganic manures should contain only incombustible or ash constituents. To support this allegation, he gives, in a separate paragraph, and in italics (Sperrschrift), the following sentence as a quotation from Mr. Lawes's paper on 'Agricultural Chemistry,' vol. viii. p. 240, of this Journal :—

"Manures are generally divided into two classes, organic and inorganic: organic manures are those which are capable of yielding to the plant, by decomposition or otherwise, carbon, hydrogen, and nitrogen. Inorganic manures are those substances which contain the mineral ingredients of which the ash of plants is found to consist."—[Translation.]

But the following is the passage as it really stands at the page referred to by Baron Liebig, and the portions given in capitals are those which are omitted by Baron Liebig in his professed quotation :—

"I NOW COME TO THE ACTION OF manures, WHICH are generally divided into two classes—*organic* and *inorganic*. ALTHOUGH THIS DISTINCTION IS BY NO MEANS SATISFACTORY, I SHALL ADOPT IT AS BEING GENERALLY UNDERSTOOD. Organic manures are those which are capable of yielding to the plant, by decomposition or otherwise, ORGANIC MATTER—carbon, hydrogen, OXYGEN, and nitrogen —CONSTITUENTS WHICH UNCULTIVATED PLANTS DERIVE ORIGINALLY FROM THE ATMOSPHERE. Inorganic manures are those substances which contain the mineral ingredients, of which the ash of plants is found to consist."

Here, then, in this which was Mr. Lawes's first paper, the classification which Baron Liebig accuses him of originating is only adopted as being already at that time "generally understood," and with a distinct protest that it is "by no means satisfactory." Yet, in order to fix the origination of the distinction upon Mr. Lawes, Baron Liebig joins together disconnected parts of a passage, and gives them, in a separate paragraph, in italics (Sperrschrift), and between unbroken inverted commas, omitting (besides less material portions) an entire sentence

given in our paper in the last Number of the Journal do show, however, that the description of plants developed has, in most cases, been much changed, and in some deteriorated, under the

which distinctly disproves the truth of the allegation in support of which the professed quotation is brought forward! Having thus moulded Mr. Lawes's sentence to suit the requirements of his argument, he goes on to say :—

"From this doctrine of the practical man it necessarily followed that a mineral manure must be one which contained *only* the ash-constituents of vegetable products, and from the composition of which ammonia-salts, as belonging to organic manures, are excluded. To be sure, in every chemical manual ammonia and its salts are treated of among inorganic substances, since they are objects of chemical manufacture, whilst organic matters cannot be produced by man; and this fact might well have led to the suspicion that ammonia was not necessarily excluded from an inorganic manure. The agricultural chemistry of the practical man was evidently a peculiar chemistry, which had no connexion with ordinary chemistry, and thus *his* theory might well find some justification, but according to *my* theory I obviously took another point of view. Mr. Lawes, indeed, mentions in his paper (p. 21), that my manures smelt of ammonia, and hence contained an ammonia-salt; but he implied that this might be a little artifice, in order to give to my manures an efficacy which, according to his interpretation of my theory, they should not possess."—[Translation.]

The following quotations, taken from several of Baron Liebig's works, will show whether he has not been accustomed to use the terms "mineral" or "inorganic" to designate the incombustible or ash-constituents, and to distinguish these from "ammonia," "ammoniacal salts," "atmospheric constituents," &c. The italicising is our own :—

"The *mineral* constituents act, as is shown by the produce of the unmanured land, without any artificial supply of *ammonia*."

"The *ammonia* increases the produce only if the *mineral* constituents be present in the soil in due quantity, and in an available form.

"*Ammonia* is without effect if the *mineral* constituents are wanting. Consequently, the action of *ammonia* is limited to the acceleration of the action of the *mineral* constituents in a given time."—*Principles*, pp. 86-7 (1855).

". . . . . the other is the action of *sulphate of ammonia* as a solvent for certain important *mineral* constituents of the soil."—Ib., p. 99 (1855).

"*Ammonia*, when used as a manure alone, and when there is a want of *mineral* constituents in the soil, is like the spirits which the labourer takes in order to increase his available labour, power, or imagination; and, like that stimulant, its action, in this case, is followed by a corresponding exhaustion."—Ib., p. 106 (1855).

"Hence it is quite certain that in our fields the amount of nitrogen in the crops is not at all in proportion to the quantity supplied in the manure, and that the soil cannot be exhausted by the exportation of products containing *nitrogen* (unless these products contain at the same time a large amount of *mineral* ingredients), because the *nitrogen* of vegetation is furnished by the atmosphere, and not by the soil. Hence also we cannot augment the fertility of our fields, or their powers of production, by supplying them with manures rich in *nitrogen*, or with *ammonia salts* alone. The crops on a field diminish or increase in exact proportion to the diminution or increase of the *mineral substances* conveyed to it in manure." —4th Edition, p. 210 (1847?).

"But, at the same time, it is of great importance for agriculture to know with certainty that the supply of *ammonia* is unnecessary for most of our cultivated plants, and that it may be even superfluous, if only the soil contain a sufficient supply of the *mineral* food of plants, when the *ammonia* required for their development will be furnished by the atmosphere."—4th Edition, p. 212 (213).

"A fertile soil must contain in sufficient quantity, and in a form adapted for assimilation, all the *inorganic* materials indispensable for the growth of plants.

"A field artificially prepared for culture contains a certain amount of *these ingredients*, and *also* of *ammoniacal salts* and decaying vegetable matter."—4th Edition, p. 169.

"The meaning of these sentences in my work is this: 'that *ammoniacal salts*

influence of the different manures; and those given further on relating to the chemical composition of the hay, and to the amount of constituents removed from the land, will lead to the conclusion that some of the manures have so forced the crop as materially to reduce the available store within the soil of some constituents which the manures themselves did not supply. On the other hand, even with 14 tons of farmyard manure per acre per annum, doubtless supplying annually much more of every mineral constituent than would be removed in the crop, the rate of increase is very little higher during the last four than during the whole seven years of the experiments.

With ammonia-salts alone (Plot 4) there has been an average increase over the seven years of about 8 cwts., and with ammonia salts and sawdust (Plot 5) of about 9 cwts. of hay per acre per annum; but over the last four years, of only about $5\frac{3}{4}$ cwts. with ammonia salts alone, and about $7\frac{1}{2}$ cwts. with the sawdust in addition. It is obvious, therefore, that, when ammonia salts were used year after year without mineral manure, there was an undue exhaustion of the mineral constituents of the soil. That this was so is confirmed, not only by the fact of the deteriorated character of the herbage, as shown by the results of the botanical examinations recorded in the last Number of the Journal, but also by the evidence relating to the chemical composition of the produce.

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alone' have no effect; that, in order to be efficacious, they must be accompanied by the *mineral constituents*, and that the effect is then proportional to the supply —not of *ammonia*, but of the *mineral* substances."—*Principles*, p. 55 (1855).

"These two paragraphs are altogether irreconcilable; for if Mr. Lawes admit that the *mineral* constituents are indispensable to plants, how can he maintain that these very *mineral* constituents are replaceable by *ammonia*, that is to say, that by means of ammonia we can altogether dispense with them?"—*Principles*, p. 89 (1855).

"It has been mentioned in the preceding part of the chapter, that animal excrements may be replaced in agriculture, by other materials containing their constituents. Now, as the principal action of the former depends upon their amount of *mineral* food so necessary for the growth of cultivated plants, it follows, that we might manure with the *mineral* food of wild plants, or, in other words, WITH THEIR ASHES [the capitals are Baron Liebig's own]; for, these plants are governed by the same laws, in their nutrition and growth, as cultivated plants themselves." —3rd Edition, p. 183 (1843).

"But the weight or amount of the crops is in proportion to the quantity of food of both kinds, *atmospheric* and *mineral*, which is present in the soil, or conveyed to it in the same time. By manuring with *ammoniacal salts* a soil rich in available *mineral* constituents, the crops are augmented in the same way as they would have been if we had increased the proportion of *ammonia* in the air."—*Principles*, p. 77-8 (1855).

These sentences will be sufficient to show whether or not Liebig is justified in now attempting to fall back, in agricultural discussions, upon the more strictly scientific meaning of the terms "mineral" and "inorganic," so as to include within them "ammonia," "ammoniacal salts," "atmospheric constituents," &c., and thus to give a new definition to his mineral theory, or rather substitute at this date for his own theory, which has proved to be erroneous, another not his own.

The experiments with nitrate of soda (Plots 6 and 7) were commenced two years later than those with the other manures, so that we have the results of only five instead of seven years to record. Unlike those with ammonia-salts alone, however, we have, so far, indication rather of progressive increase than decrease of annual effect. There is also, as yet, rather more of produce and increase from a given amount of nitrogen applied in the form of nitrate of soda (Plot 7), than from an equal amount in the form of ammonia salts (Plot 4). The description of plants developed was, moreover, very different in the two cases. These results may be partly due to the fact that the soil having less power to absorb and retain the nitric acid of the nitrate than the ammonia of the ammonia-salts, the former would probably be more rapidly diffused in the soil, and hence minister to the wants of plants whose roots take a wider range than those of the plants most benefited by ammonia salts.

The experiments with superphosphate of lime alone (Plot 3*a*), and with superphosphate of lime and ammonia-salts (Plot 3*b*), were commenced three years later than most of the others, so that the results recorded refer to the produce of four years only.

The average annual increase with the superphosphate of lime alone was little more than 2 cwts. of hay per acre; and the produce has fluctuated, from year to year, much in the same degree as that without manure, excepting that in the fourth season (1862) the produce scarcely exceeded the average without manure.

The addition of ammonia-salts to superphosphate of lime, raised the average annual produce from $28\frac{1}{4}$ cwts. to $43\frac{1}{2}$ cwts., and the average annual increase beyond the produce without manure from a little more than 2 cwts. to nearly $17\frac{1}{2}$ cwts.

When to superphosphate of lime, salts of potass, soda, and magnesia were added (Plot 8), the average annual produce was raised from $28\frac{1}{4}$ cwts. to $36\frac{1}{4}$ cwts. of hay per acre; but the increase under these circumstances consisted almost wholly, if not exclusively, of Leguminous plants—clovers, meadow vetchling, and bird's-foot trefoil. Both the average produce and average increase were rather higher during the last four years than over the whole seven years of the experiments, and there is as yet no sign of diminution. In fact, this "mixed mineral manure" supplied annually more of all the mineral constituents otherwise most likely to be exhausted than would be taken off in the increased produce of Leguminous plants.

The addition of sawdust to the mixed mineral manure (Plot 9) scarcely added at all to the produce. It should be observed, in regard to the manuring of this plot, that in 1862 the potass-salt was omitted, and a larger quantity of soda-salt substituted, and the result was (as shown in the last Number of the Journal)

a notable diminution in the proportion of Leguminous herbage, though the total yield of hay per acre was not diminished.

The addition of 400 lbs. of ammonia-salts (equal parts sulphate and muriate) to the mixed mineral manure of Plot 8 (Plot 10) increased the average annual produce over the last four years from 36¼ cwts. to 53¾ cwts. of hay, that is, by about 18½ cwts; and the average annual increase obtained by this mixture, above the produce without manure, was nearly 28¾ cwts. over the last four, and rather more than 31½ cwts. over the whole seven years. There is, therefore, when this large amount of ammonia-salt is used in conjunction with the mixed mineral manure, an indication of a slight falling off in the annual yield. In reference to this point it should be particularly borne in mind, that whilst the produce by the mixed mineral manure alone contained Leguminous herbage in amount equal to nearly one-fourth of its total weight, that grown by the mixed mineral manure and ammonia-salts contained scarcely a trace of such herbage. The produce in the latter case consisted (with the exception of a few luxuriant weeds), almost entirely of Graminaceous plants, or grasses, properly so called, which require a large amount of silica for their development; and as the manure employed contained none, the large amount of increase must have caused a considerable drain of the available silica of the soil, the limitation of the supply of which probably set a limit to the amount of increase obtained by this otherwise heavy manuring.

The addition of 2000 lbs. of sawdust per acre per annum to the mixed mineral manure and ammonia-salts (Plot 11) very little affected either the amount or the character of the produce, which was, however, rather less than without the sawdust. On this Plot 11, as on Plot 9, the potass-salt was omitted from the manure in 1862, but the amount of soda-salt increased, and about 2 cwts. less hay were obtained than on Plot 10 with the potass and without the sawdust. This difference is, however, but small; and although (not having at present at command either the analytical details relating to the first crop, or the results relating to the after-grass) we do not record the amounts of the first crop of the present season (1863), it may be mentioned in passing that Plot 11, without potass, has this year given a somewhat larger amount of Graminaceous hay than Plot 10 with it.

The general result in regard to the effects of these mixtures of mineral constituents and ammonia-salts (Plots 10 and 11) is, that, by their means, we have obtained for seven or eight years consecutively, an average produce of about 2¾ tons of hay per acre, and an average increase of about 1½ ton.

Adding to the same mixture of mineral constituents and ammonia-salts 2000 lbs. of cut wheat-straw annually, scarcely

increased the average produce of hay, notwithstanding that the straw was calculated to furnish, by gradual decomposition, besides other mineral constituents, the silicates in which the artificial mixture was deficient, and to contribute a supply of carbonic acid for the solution of the mineral constituents of the soil, and a small amount of available nitrogen also. The after-grass has, however, generally been slightly more luxuriant; and, as shown in the last number of the Journal, the description of herbage developed was somewhat different, and, perhaps, rather superior.

On Plot 13 (divided in 1862 into 13*a* and 13*b*), in addition to the mixed mineral manure, there was applied a double or very excessive amount of ammonia-salts (800 lbs.) in the first, second, third, and seventh years of the experiments, but only 400 lbs. in each of the three intermediate years, 1859, 1860, and 1861. The result of this very heavy dressing was an average over the seven years of above 3 tons of hay per acre per annum. It was somewhat less during the last four years, in three of which the single amount only of ammonia-salts was used; but in 1862 (and in the present year also) the produce was again increased with the increased supply of ammonia-salts, though by no means in proportion to that increased supply. As shown in the last number of the Journal, the heavy crops grown on this plot contained not a trace of Leguminous plants; but, with the exception of a few very luxuriant weeds, they consisted almost entirely of comparatively few species of very free-growing grasses, in an over-luxuriant and very stemmy condition.

As just alluded to, in 1862, that is, after the experiments had been continued for six seasons, this Plot 13 was divided into two equal portions; and to one of these (13*b*) 200 lbs. of a silicate of soda, and 200 lbs. of a silicate of lime, were applied per acre, in addition to the manures of Plot 13*a*. This led to scarcely any appreciable increase in the first year of the application, but the results of the present or second season show an increased produce of about 6 cwts. of hay per acre where the silicates were used; and it was obvious to the eye that some of the grasses were more luxuriant. It remains to be seen what will be the effects of this addition in future years. There is no doubt that the heavy dressing of 13*a*, without silicates, forcing, as it does to such a degree, the luxuriant growth of Graminaceous plants, which require more silica than herbage of any other description, must tax very severely the store of available silicates within the soil. Additional evidence will be given on the point further on; but it may be here remarked in passing, that the forcing of very heavy crops of hay by the use of artificial manures alone is by no means recommended.

It would be far too expensive to supply in this way all the constituents that are requisite for the production of such crops without undue exhaustion of the soil, or deterioration in the character of the herbage. Artificial manures can, as a rule, only be used with advantage and economy for the hay crop, when the land receives periodically a dressing of stable or farmyard manure. Such manure restores the mineral constituents taken from the land in the crop more completely, and some of them more economically, than any other; it at the same time supplies a large amount of available nitrogen, and of organic matter yielding by its decomposition carbonic acid, and is calculated to favour a more complex and generally a superior description of herbage.

Plot 14 received the same description and amount of mineral manure as Plots 8, 10, 12, and 13*a*, and, in addition, nitrate of soda containing about half the amount of nitrogen supplied in the ammonia-salts of Plot 10; and Plot 15, with the same mineral manure, had, in addition, double the amount of nitrate—that is, about the same amount of nitrogen as that in the ammonia-salts of Plot 10. These experiments, like those with nitrate of soda alone, were commenced only in 1858, two years later than most of the series. The figures show an average over the five years of 44 cwts. of hay per acre per annum with the smaller amount of nitrate, and the mineral manure, and of 51½ cwts. with the larger amount, against 56¾ cwts. with the same mineral manure, and ammonia-salts equal in nitrogen to this larger amount of nitrate.

Ammonia-salts, in conjunction with the mixed mineral manure, have, therefore, given a larger amount of produce than an equal amount of nitrogen in the form of nitrate of soda. The description of herbage developed was, however, strikingly different in the two cases, and very different also with the smaller and the larger amounts of nitrate, as will be found by reference to the last number of the Journal. It should be added, that there is as yet no evidence of diminution of produce from year to year where the nitrate (either in the larger or the smaller quantity) was used in conjunction with the mixed mineral manure.

The plots manured with farmyard manure remain to be considered. The amount annually supplied (14 tons) would contain more of every mineral constituent, and considerably more nitrogen, than the produce obtained by its use, besides a large quantity of organic matter yielding by its decomposition carbonic acid and other products. When the farmyard manure was used without the addition of ammonia-salts, the average annual produce amounted to only about 42½ cwts. of hay, or to less than 1 ton above that without manure, and to considerably less than was

obtained by the most active artificial manures. The description of herbage was, however, very different—that grown by the farmyard manure being very much more complex and, upon the whole, superior in quality to that grown by the very active artificial Manures.

The addition of 200 lbs. of ammonia-salts to the comprehensive, but not very rapidly active, farmyard manure increased the average annual produce by only about 6 cwts. of hay; still, therefore, giving a produce considerably less than that obtained by the most active artificial manures. Nor did the addition of ammonia-salts improve the character of the herbage, which was more Graminaceous, consisted in larger proportion of comparatively few species, and was much more stemmy, than when the farmyard manure was used alone. The number, and proportion in the produce, of miscellaneous or weedy plants was, however, considerably reduced under the influence of the ammonia-salts.

Reviewing the results of the whole series, it is observed that the average produce without manure is slightly higher over the last four than over the whole seven years of the experiments; indicating, therefore, that the conjoint resources of soil and season were at least equal, if not more favourable, during the later years. A similar result is observed in the case of the farmyard manure plot, and of the plots where there was a liberal supply of mineral constituents without ammonia in the artificial manures; but where ammonia-salts were used in large quantity, either alone or in conjunction with the mineral manures, there was a tendency to a rather diminished rate of increase as the experiments proceed. The indication, so far as the gross amount of hay obtained is concerned, is, however, as yet but slight; and in the present season (1863) the produce on Plot 13*a*, where the very excessive amount of ammonia-salts was used, and where the mineral manure contained no silicates, is heavier than in any previous season. The chief indication of exhaustion of certain constituents, or of deterioration of the produce, is afforded by a consideration of the description and composition of the herbage developed. Where nitrate of soda is used, whether alone or in conjunction with the mixed mineral manure, there is as yet no evidence of progressive falling off in the annual yield.

Produce of After-Grass.

Table II. (p. 531) shows the amounts of hay per acre to which the after-grass of each of the last four seasons is estimated to be equivalent, and also the annual average over the four and over the seven years of the experiments. As already mentioned, the after-grass was always consumed by sheep (once or twice, as might be

required), so that the estimation of the quantity of hay to which i corresponded is necessarily a matter of calculation merely. The plan adopted was—to fold sheep on each plot, the number depending upon the amount of grass; to move the hurdles day by day as required; to note the time taken to consume the produce; and then to estimate, approximately, the amount of hay to which the consumed grass was equivalent, on the assumption that each sheep would, on the average, consume grass equal to 16 lbs. of hay per head per week. Such an estimate, though only approximative, still affords a very useful indication of the relative, if not the actual, amounts of after-grass of the respective plots. In 1860 and 1862 it was so eaten off twice, but in each of the other years only once.

It will be obvious that, as the animals would return to the land by far the larger proportion of both the mineral constituents and the nitrogen of the produce, to serve as manure for the first crop of the succeeding season, and so on each year, the amounts of hay estimated as above described cannot be added to the actual amounts of the first crop, and the sum reckoned as the annual yield on the respective plots. The latter would, however, it is true, be somewhat higher than the amount of first crop hay alone.

Judging from the relative amounts of first-crop hay where the mineral constituents would probably be in relatively large amount (without manure, with purely mineral manure, or with farmyard manure, for example), and where, therefore, the produce would be the more directly limited by the conditions of season, it would be concluded that these were the least favourable in 1859, more so in 1860, and still more favourable, and about equally so, in 1861 and 1862. Judging, in the same way, from the estimated amounts of hay corresponding to the after-grass, it would appear that the period of its growth was the most favourable in 1860, and nearly equally so in 1862 (these being the two years in which the produce was eaten off twice), that it was somewhat less favourable in 1861, and less so still in 1859. But it is obvious that the influence of accumulation, or of non-exhaustion of previous manuring, as well as that of season, has to be taken into account as affecting the produce in one year compared with another. The less the exhaustion of the more active manurial constituents by the growth of the first crop, the greater will be the accumulation for the after-growth, though their activity will greatly depend on the climatic conditions. And, again, variations in the amount of after-grass will affect the amount of manure left by the animals on the surface of the land, to be washed in and serve for the first crop of the succeeding year; though it will be obvious that any effects of such variation will

be due to the condition and distribution of the constituents rather than to any actual loss or gain of them.

The produce of after-grass was, upon the whole, the largest in 1860, when it was eaten off twice—the first time early in September. In accordance with this, the records show that in the months of July and August the maximum temperature was comparatively low, the minimum temperature moderate, the mean temperature and the range of temperature both low, and the fall of rain and the number of days on which it fell above the average. In 1862, also, the grass was fed off twice, commencing the first time soon after the middle of August; and the characters of the July and August of that season more nearly approached those of 1860, as above quoted, than did those of either of the other years. In 1859 the after-growth was both the smallest in amount and the latest, the sheep not being put upon the land at all until November 14; and coincidently with this there was comparatively high temperature, and somewhat below the average amount and distribution of rain—especially during the first few weeks after the removal of the hay-crop. In 1861 the amounts of after-grass were more than in 1859, but less than in either 1860 or 1862, and the produce was eaten off only once—namely, early in October. The characters of the season in regard both to temperature and amount of rain were less favourable for succulent growth than in either 1860 or 1862, and as to amount of rain less favourable than in 1859 also. In regard, however, to the distribution of rain, or the number of days on which it fell, the month of July (1861) was far above, and that of September about, the average.

From these few observations it will be obvious that the variations in the amounts of after-grass in one year compared with another were very directly dependent on the characters of the seasons; they were, in fact, much more so than on the greater or less amounts of hay removed in the first crop. It is, indeed, remarkable how little was the fluctuation in the produce of first-crop hay from season to season, with one and the same manure, compared with that of the after-grass. The character of the herbage of the first crop was, however, remarkably affected by the character of the season of its growth; one and the same amount of produce representing a very different description of hay in the different years. The variation manifested itself not only in a difference in the prevalence of particular plants, but more strikingly in the character of their development—the relative tendency to give a leafy or stemmy, base-leafed or stem-leafed, early or late, ripe or unripe produce. But the gross amounts of after-grass varied exceedingly from

year to year. In 1860 they amounted on the average to twice as much as in 1859; in 1861 to considerably less than in 1860, but generally to at least 1½ time as much as in 1859; and in 1862 in most cases to nearly as much and in some to considerably more than 1860.

Without manure, the after-grass of 1859 was estimated as equal to something less than 8 cwts., that of 1860 about 19 cwts., that of 1861 nearly 14 cwts., and that of 1862 about 15½ cwts. of hay. With farmyard manure the amounts were scarcely 10 cwts. in 1859, more than 21½ cwts. in 1860, nearly 16 cwts. in 1861, and over 21 cwts. in 1862. With the heavy dressings of mixed mineral manure and ammonia-salts they ranged from about 11 to nearly 15 cwts. in 1859, from over 21 to over 22 cwts. in 1860, from about 16 to about 18 cwts. in 1861, and from about 17 to about 24 cwts. in 1862.

Comparing more directly the effects of the different manures on the amounts of after-grass, it is seen that the quantities varied, in 1859 from under 8 cwts. without manure to about 14¾ cwts. with the heaviest artificial manuring; in 1860 from about 19 cwts., to about 22 cwts.; in 1861 from about 13¾ cwts. to over 18 cwts.; and in 1862 from about 15½ cwts. to about 24¼ cwts.

The facts relating to the after-grass show, then, that the amounts varied very much both according to season and manuring, and that, when both were favourable, they were frequently equivalent to more than one ton of hay. Taking the average of the seven years, the after-grass without manure was estimated as equivalent to about 12½ cwts. of hay per acre per annum, and that with the heaviest artificial manuring at nearly 19½ cwts.

Chemical Composition of the Hay.

In our former report on the composition of the hay grown by the different manures in the earlier years of the experiments (vol. xx., part 2), we treated of the proportions of—nitrogenous substance, fatty matter, woody fibre, other non-nitrogenous vegetable compounds, mineral matter (ash), total dry substance, and water; and to that more complete consideration of the subject we refer the reader. In treating, on the present occasion, of the composition of the hay grown in the fourth, fifth, sixth, and seventh seasons, attention will be confined to the proportions of dry matter, of mineral matter (ash), and of nitrogen; and a few general observations on the circumstances affecting the composition may here be made, thereby rendering the indications of the results themselves the more readily understood.

Comparing the hay of one season with that of another, a high

percentage of dry matter may simply indicate dry weather at the time of cutting and during the making; or, it may also indicate a relatively high degree of maturity or ripeness. Comparing the produce of one plot with that of another differently manured, but grown in the same season, and cut and made under the same conditions of weather, a relatively high percentage of dry substance indicates a comparatively high degree of ripeness or maturity, and most probably a stemmy rather than a leafy condition of development.

As the percentage of mineral matter or incombustible constituents, even though the same in the fresh hay, may be very different in its dry substance, according to the proportion of the latter, and as the percentage in the dry substance indicates much more clearly the probable condition of the hay, it is important that it, as well as that in the fresh hay, should be considered. Other things being equal, a high percentage of mineral matter in the dry substance indicates a leafy rather than a stemmy development, and an immature rather than a ripe condition. The percentage of mineral matter in the produce is also more or less, though comparatively slightly, affected by the liberality or deficiency of available mineral constituents within the soil; but as the tendency of the development is very much affected by these circumstances, the effects are, in part at least, indirect; that is to say, the relative supply of mineral constituents, affecting as it does the relative development of leaf and stem, and the tendency to ripen, the percentage of mineral matter in the produce is in its turn affected accordingly, as above referred to.

The percentage of nitrogen in the dry substance of the hay may depend on several different conditions. The condition of manuring being the same, a high percentage in the produce of one year compared with that of another will most probably indicate a high proportion of leaf to stem, or a green and succulent rather than a ripened condition. Comparing the produce by one manure with that of another in one and the same season, the percentage may again depend on various circumstances. Leguminous plants, and some weeds, are much richer in nitrogen than Graminaceous plants in an equal condition of ripeness; leafy matter generally contains a higher percentage than stemmy; succulent and unripe produce a higher one than that which is ripe (all of which conditions are much influenced by the character of the manure); and further, when in the succulent and unripe condition, as produce cut for hay to a certain extent is, the percentage of nitrogen is generally pretty directly affected by the relative available supply of it within the soil. That is to say, an excessively nitrogenous manure will—other things being equal—give a relatively high percentage of nitrogen at an

equal stage of growth or maturity; but as, within limits, and under favourable conditions of soil and season, a moderate supply of nitrogen favours the ripening tendency, the crop more liberally dressed with nitrogenous manure may, at the same period of time, be at a more advanced stage of growth, and it might not then, as it otherwise would, show a higher percentage of nitrogen in its dry substance.

Percentage of Dry Matter in the Hay.

Table III. (p. 532), gives, for each plot, the percentage of dry matter in the hay as carted from the land, in each of the last four years, also the average percentages over the four, and the whole seven years of the experiments.

Comparing the produce of one year with that of another, the order of highest percentage of dry matter was—1859, 1861, 1860, and 1862; and it may be observed that this result is quite consistent with the characters of the respective seasons for some time before cutting, and during the making the hay. The percentages of mineral matter in the dry substance will, however, show, that there was a real difference in the ripeness of the produce, as well as in its mere condition of dryness or dampness according to the weather immediately before the cutting and during the making. Thus, the produce of 1859 and 1861, with higher percentages of dry matter than in that of 1860 or 1862, contained lower average proportions of mineral matter in the dry substance, indicating a greater degree of maturity.

The percentage of dry matter in the produce varied very much less comparing that grown by different manures in the same season, than comparing season with season. In fact, when it is borne in mind how many circumstances affect the condition of such complex and indefinitely ripened produce as hay according to the manure employed, it is only what we should expect, to find that the difference in the condition of the produce of two comparable plots may vary, or even be reversed, according to the characters of the season; for, not only will the proportions of Leguminous, Graminaceous, or other herbage (which are each somewhat differently affected in development according to season) be very different according to the manure employed, but the prevalence of one Graminaceous plant over another, the tendency to leafy or stemmy growth, and the relative condition of ripeness, will also greatly vary. Thus, with a hot and ripening season, the addition of nitrogenous to mineral manure may so increase the fixation of carbonaceous substance as to give a produce containing a higher proportion of dry substance; whilst in a wetter and colder season the effect would probably be to give a relatively leafy and succulent

growth, containing a lower percentage of dry matter. Accordingly, the relative proportions of dry matter in the produce of one plot compared with that of another are seen to vary more or less from season to season. Still the general, though not the invariable, result is found to be that, in comparable cases, the larger the relative supply of available mineral constituents, the higher will be the percentage of dry matter in the produce at the time of cutting, due mainly to the greater tendency to ripen under such conditions. The columns showing the average percentage of dry matter in the produce of each plot over the four and over the seven years afford sufficient illustration on this point.

The general result in regard to the proportion of dry matter in the hay is, that variation of season has very much more influence than variation in manure in one and the same season; that, so far as manures have an influence, those which tend most to stemmy produce, and to ripeness, generally give the highest proportion of dry substance; that a relatively liberal supply of mineral manure favours this tendency; and, that the greater the excess of nitrogenous manure (provided the supply of mineral constituents be not insufficient for luxuriant growth), the lower, other things being equal, will be the proportion of dry matter in the produce.

Percentage of Mineral Matter (Ash) in the Hay.

Table IV. (p. 533) shows the percentages of mineral residue obtained on burning the dry substance to ash, and the results approximately represent the relative proportions of mineral constituents. The left division gives the percentages in the hay as taken from the land, and the right those in the dry substance of the hay. The latter of course give the best view of the relations of the mineral to the other solid constituents of the produce.

Comparing season with season, there were much lower proportions of mineral matter in the dry substance of the riper and drier produce of 1859 and 1861, than in that of the more backward and moister produce of 1860 and 1862; and, of the four seasons, the produce of 1862, which yielded the lowest proportion of dry substance, shows generally, but not invariably, the highest proportion of mineral matter in that dry substance.

Comparing plot with plot, the percentage of mineral matter in the dry substance of the hay has a very obvious connexion with the conditions and characters of growth.

The general result in regard to the proportion of mineral matter in the dry substance of the hay may be stated to be, that it was the higher the more liberal the relative supply of mineral constituents in the manure, the less Graminaceous, or the less