III. *Agricultural, Botanical, and Chemical Results of Experiments on the Mixed Herbage of Permanent Grass-land, conducted for many years in succession on the same Land.*—Part III. *The Chemical Results.—Section I.*

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Introduction.

The Experiments on the Mixed Herbage of Grass-land were commenced in 1856, and are still in progress, so that the present is the 44th year of their continuance. About seven acres are devoted to the purpose; and since the first few years there have been 20 main plots, some of which have temporarily been subdivided. There are two continuously unmanured plots, and the remainder have respectively received different descriptions or quantities of manures of known composition. During the first 19 years, first crops only were removed from the land; the second crops being fed by sheep, or if there were not sufficient for this, they were cut and spread. In the twentieth and subsequent years the second crops were cut, removed, and weighed, excepting in a few seasons when the produce was extremely small; in which cases it was cut and spread on the respective plots.

In all cases of both first and second crops, the dry matter and the ash, and in most the nitrogen, have been determined. In selected cases, determinations have been made of the amount of nitrogen existing as albuminoids, and in some, of the amount of "crude woody-fibre," and of crude fatty matter. More than 200 complete analyses of the ashes of the produce have also been executed; besides nearly 40 of the ashes of other crops, the results of which are given and considered. All the ashes have been prepared at Rothamsted, and the analyses made by Mr. R. Richter; in the earlier years in the Rothamsted Laboratory, but subsequently in his own laboratory at Charlottenburg, Berlin. Lastly, samples of the soil of every plot, in some cases at different periods, and generally representing the first, second, third, fourth, fifth, and sixth, depths of nine inches each, or to a total depth of 54 inches, have been collected; and they have been chemically examined in various ways.

Even in the first years of the experiments, it was noticed that those manures which were the most effective with gramineous crops grown separately on arable land, were also the most effective in bringing forward the grasses proper in the mixed herbage; whilst those which were the most beneficial to leguminous crops grown separately, also characteristically developed the leguminous species of the mixed herbage, and *vice versâ*. Further, it was observed, that there was great variation is the predominance of individual species among the grasses, and also among the representatives of other Orders. Accordingly, in the early years some attempt was made to conduct botanical analyses of carefully taken samples of the produce of some of the plots. From year to year, however, the plots became more and more characteristic; and in the seventh season, 1862, it was decided to undertake much more complete botanical separations; and such complete separations in samples from every plot have been made at four periods, at intervals of five years—namely, in 1862, in 1867, in 1872, and in 1877. Besides these complete separations

into individual species, in samples from every plot in the four seasons enumerated, partial separations have been made in the produce (sometimes of both first and second crops) of selected plots, in many seasons, into the three main divisions of *Gramineous herbage, Leguminous herbage, and " Miscellaneous" herbage.*

It will be obvious that the records of such an enquiry, extending over so many years, and involving laborious agricultural, botanical, and chemical details, must be extremely voluminous; and, before the publication of our first report, it was decided 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.

Our first Report under the heading of "*The Agricultural Results*" was presented to the Royal Society in June, 1879 ('Phil. Trans.,' Part 1, 1880). The illustrations were chiefly, but not exclusively, confined to the results obtained in the first twenty years of the experiments. There were given, for each of the about twenty plots, the average produce of first crops of hay per acre, over the first ten, the second ten, and the total period of twenty years; and also the amounts of nitrogen, and of total mineral matter (ash), in that produce. It may be stated that, even without manure, the produce of hay varied from year to year according to season, from about 8 cwt. to nearly 39 cwt. per acre, the average yield being about 23 cwt. per acre per annum. On the other hand, the plot the most heavily artificially manured, and yielding the highest amounts of produce, gave an average of about 64 cwt. of hay per acre per annum, with a range from year to year, from under 40 cwt. to nearly 80 cwt.; whilst, between these extremes, there was very great variation exhibited on the other differently manured plots. Obviously, too, there was, under these circumstances, a very wide range in the amounts of nitrogen and of mineral matter taken up in the different cases. There were, moreover, very striking differences in the botanical character of the herbage; not only so far as the presence, or absence, or prominence, of individual species was concerned, but in the character of their development as to leafiness or stemminess, succulence, or maturation.

Our second paper was presented to the Royal Society in June, 1880 ('Phil. Trans.,' Part 4, 1882), and related to "*The Botanical Results.*" The complexity of this branch of the subject will be readily understood when it is stated that the total number of species which have been observed on the plots is 89, comprised in 63 genera, and 22 Orders; whilst, to take some of the more important Orders, there have been found—of *Gramineæ* 20 species, representing 14 genera; of *Leguminosæ* 10 species, of 5 genera; of *Compositæ* 13 species, of 12 genera; of *Umbelliferæ* 5 species, of 5 genera; of *Polygonaceæ* 3 species, of 1 genus; of *Ranunculaceæ* 5 species, of 1 genus; and of *Plantaginaceæ* 2 species, of 1 genus. The majority of the 22 Orders are, however, represented by only one two or three species, and only 1 genus

each. To take a special example, it may be stated that the herbage of the Unmanured plot comprises about 50 species, and that 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, not more than 15 species have been observable; indeed, on some, after a number of years, no more than this are ever traceable. Then there is the greatest possible diversity in the character of the development, as to leafiness, stemminess, depth of green colour, maturation, etc., according to the season, and to the manuring.

The Chemical Results.

The influence of season and of manuring on the botanical composition of the Mixed Herbage of Grass-land was very fully illustrated in Part II—*On the Botanical Results*—and it has been briefly indicated above. We now have to consider their influence on the chemical composition of the herbage. It happens, however, that the chemical composition is itself very directly dependent, not only on the seasons and on the supplies within the soil, but very prominently also on the description of plants encouraged, and on the character of their development; so that it comes to be essential to the proper interpretation of the variations in the chemical composition, to bear in mind the differences in the botanical composition with which those variations are associated.

We have, therefore, constructed a summary Table I. (pp. 144–145), which brings to view as fully as is practicable within such limits, but still very imperfectly, the characteristic differences in the botanical composition induced under the different conditions as to manuring, the influence of which on the chemical composition it is our present object to illustrate.

Brief Summary of the Botanical Composition.

As during the first nineteen years, first crops only were removed, whilst in the twentieth and subsequent years, second as well as first crops were removed whenever the growth was sufficient; and as also, the botanical separations were both more frequent and more complete during the earlier years, it will conduce to simplicity and clearness, in the first place to limit our illustrations as to the chemical composition of the mixed herbage, mainly to the period when first crops only were removed.

It is to be understood, as stated at the head of the Table (I), that the results given, indicating the botanical character of the produce of the different plots, are the averages according to complete botanical separations at three periods only—namely, in 1862, 1867, and 1872. Reference to the table will further show, that on the left hand there are given the numbers of the experimental plots, and a brief description of the conditions of the manuring of each. Then follows a record of the average

number of species found on each plot, referrible respectively, to the *Gramineæ*, the *Leguminosæ*, and to other Orders collectively, classed together for convenience, as "*Miscellaneous species.*" Next is shown the proportion per cent. by weight, of the produce due to each of these three main descriptions of herbage; and lastly, the average quantities of produce per acre on each plot, referrible to each of these three main divisions of the herbage, reckoned according to the amounts of produce of the three years of separation only.

As a preliminary to the discussion of the chemical composition of the produce of each plot, attention will be directed to the actual and comparative botanical character of the herbage as illustrated by the results given in the table. But it will facilitate a conception of the bearing of the questions which we have to consider if the character of the results given in the table are here indicated in broad outline.

It will be seen that the first *Group* of plots includes the continuously unmanured Plot 3, the one which received farmyard manure for eight years and was afterwards left unmanured (Plot 2), and the one which for the same number of years received farmyard manure and ammonium-salts in addition, and afterwards the ammonium-salts alone (Plot 1). Whilst the continuously unmanured plot showed an average of 48 species, the others maintained, respectively, only 39 and 33 species; and the table further shows that the great reduction was in the species referrible to the various Orders other than the Gramineæ and the Leguminosæ. Then the average percentage by weight of herbage referrible to Gramineæ, was in the three cases 68·27, 79·86, and 85·87; that of Leguminosæ was 7·48, 2·83, and 0·50 per cent.; and that of species belonging to other Orders was 24·25, 17·31, and 13·63. Lastly, with the much greater amount of total produce per acre on the manured plots, especially the one with ammonium-salts as well as farmyard manure, there was, on the latter, much more than twice as much gramineous herbage per acre, scarcely any leguminous, but nearly as much referrible to other Orders, as on the unmanured plot.

The second *Group* includes the plots where nitrogenous manures alone were used. There are in the three cases, 36, 40, and 39 species. There is a range in the percentage of the gramineous herbage of 80·96, 79·01, and 76·78; and of 18·74, 20·69, and 22·39, in the miscellaneous herbage; whilst the leguminous in no case reaches 1 per cent.—in fact it is practically excluded. And, as the columns of produce per acre show, the hay was very prominently gramineous, contained scarcely any leguminous, but a fair amount of miscellaneous herbage.

The third *Group*, on the other hand, with purely mineral manures, that is without any nitrogen, shows pretty uniformly a high number of species—42, 47, 38, and 42. But, as without manure, very low percentages of gramineous herbage—57·59, 69·62, 71·69 and 67·30; whilst the leguminous herbage comes into great prominence where there was a liberal supply of potash, and the miscellaneous where there was no such supply.

TABLE I.—Summary of—Number of Species, per cent. by weight, and produce per conditions of manuring. Averages—according to bot

Plots.	Description of Manure (commencing 1856).	No. of separations.	Number of Species. Gramineæ.	Number of Species. Leguminosæ.
	GROUP 1—Plots without Manure, or with Farmyard Manure.			
			No.	No.
3	Unmanured continuously	3	17	4
2	Farmyard Manure 8 years, Unmanured 10 years	3	16	4
1	Farmyard Manure, and Ammonium-salts (= 43 lb. Nitrogen) 8 years; Ammonium-salts alone (= 43 lb. Nitrogen) 10 years	3	16	4
	GROUP 2—Plots with Nitrogenous Manures alone.			
5	Ammonium-salts (= 86 lb. Nitrogen)	3	16	4
15*	Nitrate of Soda (= 86 lb. Nitrogen)	3	17	4
17*	Nitrate of Soda (= 43 lb. Nitrogen)	3	16	4
	GROUP 3—Plots with Mineral Manures alone.			
7	Mixed Mineral Manure including Potash	3	17	4
4-1†	Superphosphate of Lime	3	16	4
8	Mixed Mineral Manure { 6 years with Potash	1	17	4
	Mixed Mineral Manure { 12 years without Potash	2	17	4
	Total Period	3	17	4
	GROUP 4—Plots with Nitrogenous and Mineral Manures together.			
9	Mixed Mineral Manure, and Ammonium-salts (= 86 lb. Nitrogen)	3	14	2
13	Mixed Mineral Manure, Ammonium-salts (= 86 lb. N.), and Cut Wheat Straw	3	15	3
11-1	Mixed Mineral Manure, and Ammonium-salts (= 158 lb. Nitrogen)	3	13	1
11-2	Mixed Mineral Manure, and Ammonium-salts (= 158 lb. N.); also Silicates 1862 and since	3	14	0
14*	Mixed Mineral Manure, and Nitrate of Soda (= 86 lb. Nitrogen)	3	14	3
16*	Mixed Mineral Manure, and Nitrate of Soda (= 43 lb. Nitrogen)	3	16	4
4-2†	Superphosphate, and Ammonium-salts (= 86 lb. Nitrogen)	3	14	3
10	Mixed Mineral Manure, and Amm.-salts (= 86 lb. N.) { 6 years with Potash	1	16	2
	Mixed Mineral Manure, and Amm.-salts (= 86 lb. N.) { 12 years without Potash	2	15	2
	Total Period	3	15	2
	SOME other Plots.			
6	Ammonium-salts (= 86 lb. Nitrogen) 13 years	2	15	4
	Mixed Mineral Manure alone including Potash 5 years	1	17	4
	Total Period	3	15	4
19	Nitrate of Soda (= 43 lb. N.), Sulph. Potash and Superphosphate (commencing 1872	1	16	4
20	Nitrate of Potash (= 43 lb. N.), and Superphosphate (commencing 1872)	1	15	5

* Commenced in 1858. † Commenced in 1859; 1856-8 sawdust only, but practically without effect.

acre, of Gramineous, Leguminous, and "Miscellaneous" Herbage, under different anical separations at 3 periods, 1862, 1867, and 1872.

Number of Species (continued).		Proportion per cent. by weight.			Calculated Produce per acre. (Average of years of separation only.)				Plots.
Miscellaneæ.	Total.	Gramineæ.	Leguminosæ.	Miscellaneæ.	Gramineæ.	Leguminosæ.	Miscellaneæ	Total.	
Group 1—Plots without Manure, or with Farmyard Manure (continued).									
No.	No.	Per cent.	Per cent.	Per cent.	lb.	lb.	lb.	lb.	
27	48	68·27	7·48	24·25	1,822	191	663	2,676	3
19	39	79·86	2·83	17·31	3,632	110	794	4,536	2
13	33	85·87	0·50	13·63	4,309	27	653	4,989	1
Group 2—Plots with Nitrogenous Manures alone (continued).									
16	36	80·96	0·30	18·74	2,611	9	605	3,225	5
19	40	79·01	0·30	20·69	3,437	14	893	4,344	15
19	39	76·78	0·83	22·39	3,300	34	950	4,284	17
Group 3—Plots with Mineral Manures alone (continued).									
21	42	57·59	25·72	16·69	2,524	1,114	735	4,373	7
27	47	69·62	4·74	25·64	1,998	115	742	2,855	4-1
17	38	71·69	19·32	8·99	3,243	874	407	4,524	
21	42	67·30	8·42	24·28	2,124	272	800	3,196	} 8
20	41	68·76	12·06	19·18	2,497	473	669	3,639	
Group 4—Plots with Nitrogenous and Mineral Manures together (continued).									
13	29	85·95	0·10	13·95	5,012	6	796	5,814	9
10	28	90·72	0·24	9·04	5,879	15	567	6,461	13
7	21	94·11	0·01	5·88	6,149	1	383	6,533	11-1
5	19	96·39	...	3·61	6,599	...	245	6,844	11-2
12	29	92·21	0·63	7·16	5,889	40	445	6,374	14
15	35	81·34	3·83	14·83	4,235	185	778	5,198	16
14	31	85·03	0·05	14·92	3,467	2	632	4,101	4-2
13	31	85·45	0·12	14·43	5,281	7	892	6,180	
8	25	88·66	0·05	11·29	4,108	2	546	4,656	} 10
10	27	87·59	0·07	12·34	4,499	4	661	5,164	
Some other Plots (continued).									
15	34	71·59	0·19	28·22	2,792	8	1,022	3,822	
18	39	79·23	1·58	19·19	2,236	45	541	2,822	} 6
16	35	74·14	0·65	25·21	2,607	20	862	3,489	
21	41	89·35	2·51	8·14	4,010	113	365	4,488	19
22	42	87·12	2·04	10·84	3,757	88	467	4,312	20

Then in the fourth *Group*, where nitrogenous and mineral manures were used together, there is a greatly reduced number of species; in one case only 21, and in another only 19, whilst in recent years neither of these plots has shown more than 15 species. But, in all cases within this group, the percentage of gramineous herbage is very high; in four over 90, and in one case 96·39; whilst subsequently, the herbage has become still more exclusively gramineous. It will be seen, too, that with such abnormal predominance of the grasses, the leguminous herbage is in most cases practically excluded, and that due to other Orders is in comparatively small amount.

Lastly, the columns giving the quantities per acre of the different descriptions of herbage show, that the amount of gramineous herbage ranged from 1822 lb. without manure (plot 3), to 6599 lb. with the full mineral manure and an excessive amount of ammonium-salts annually applied (plot 11–2). t will be further seen that the produce per acre of leguminous herbage ranged from none at all with the highest mineral and nitrogenous manuring, to 1114 lb. with the full mineral manure without nitrogen (plot 7). Again, the amount of herbage referrible to other Orders ranged from only 245 lb. to about four times as much.

Nor do these numerical records adequately represent the differences in the character of the herbage in the various cases. Not only are there the great differences which the table shows, in the number of species, and in the predominance of plants of different Orders, but the character of development of the plants, that is the tendency to leafy or merely vegetative growth on the one hand, or to stem- and seed-formation and maturation, on the other, varies very greatly, and is associated with characteristic differences in chemical composition; whilst of these characters of the herbage no numerical record can be given.

These few illustrations are sufficient to impress upon the mind how very varied are the botanical conditions with which are associated differences in the chemical composition of the Mixed herbage of grass-land.

In further illustration of the influence of character of growth on the chemical composition of vegetable produce, it will be well to call attention to some points that have been established as to the influence of season and of manuring on the composition of some individual crops grown separately. Thus, in the case of ripened crops, such as wheat for example, we have found that the composition of the grain may vary very much more when grown with the same manure in different seasons, than with very different manures in the same season. That is to say, under the influence of whatever manure the grain was grown, it had, within narrow limits, a uniform composition, provided the conditions of the season were conducive to its perfect maturation. Indeed, such variations in the composition as there were, were only due to variations in the supply by manure in so far as these, under the influence of the season, affected the perfect ripening of the seed. In fact, any difference in the organic composition of the grain depended on the adaptation of heat and moisture to the stage of development of the plant, which would itself vary according to its condition as to luxuriance

or otherwise, as affected by the manure. Hence, the relative amounts of the nitrogenous matters, the nitrogen of which is derived from the soil, and of the non-nitrogenous matters, the carbon of which is derived from the atmosphere, will vary within certain limits, but only very slightly if the crop be well ripened. With considerable variation in the maturing conditions, however, such as occur in different seasons, there may be considerable difference in the organic composition, as indicated by a higher or a lower percentage of nitrogen, or in other words, a less or a greater formation of the non-nitrogenous constituents in proportion to the amount of nitrogenous substance accumulated.

Again, so far as the mineral, or ash-constituents are concerned, it was found that whilst the percentage of potash and phosphoric acid, for example, might be very uniform under conditions of exhaustion on the one hand, or of excessive supply on the other, provided the grain were well ripened, it might vary considerably under the influence of equal conditions as to supply, but under different conditions of season, that is of maturation. In fact, the variation in the mineral composition, like that in the organic composition, depended on the condition of the ripening—indeed it depended largely on the difference in the organic composition.

But, although there was found such general uniformity in the composition of the ripened grain, under the most opposite conditions of supply within the soil, it was far otherwise in the case of the straw. The composition and especially the mineral composition of the straw, and more still that of the total produce, grain and straw together, much more closely reflected the supply by manure. That is to say, the growing plant had taken up from the soil to a certain extent what it found available there, and whether this were only little, or greatly, in excess of the requirements for seed-formation, the amount so appropriated would be limited, and comparatively uniform in composition, the remainder being accumulated in the straw, if not eliminated by the roots.

Such, then, is the influence of the supply by the soil itself, or by manure, on the composition of a ripened crop. The composition of the entire plant reflects more or less closely the supplies at its command; but the final and definite product—the ripened seed—has a fairly uniform composition; whilst the composition of the straw may vary within very wide limits according to the supply.

We should expect, therefore, when the object of cultivation is not the ripened product, but an unripened one, such as leafy herbage; or what may be called an intermediate one, such as root-crops or potatoes, that there would be great variation in composition according to the manure applied, that is according to the supplies at the disposal of the growing plant; and such is found to be the case, both so far as the nitrogen, and the mineral constituents are concerned.

If, then, it be the case that the entire plant, even of a ripened crop, shows wide variation in composition according to the supplies within the soil, and that individual crops grown separately which are not allowed to ripen, also show very wide variation

according to the supplies at their command, it would be expected when the product is such as that of the mixed herbage of grass-land, which is not only not a ripened one, but one which includes a great variety of plants, with very various habits, and range and character of roots, that its composition would vary very greatly indeed according to the soil conditions provided, and to the seasons.

Summary of the Chemical Composition of the separated Gramineous, separated Leguminous, and separated other herbage, of the mixed produce of Grass-land.

It is obviously desirable in the first place to ascertain whether there is any general and characteristic distinction between the chemical composition of the three main descriptions of herbage—the gramineous, the leguminous, and the miscellaneous—comprised in the mixed produce of grass-land. So far as nitrogen, and total mineral matter (ash), are concerned, the point is illustrated in the summary of results in Table II. below, which gives the average percentages of these in numerous samples of the separated gramineous, separated leguminous, and other herbage collectively classed for convenience as "*miscellaneous.*" As the table shows, the results relate to the separated herbage of the produce (1st crops) grown under three very different conditions as to manuring, and, for each condition, the figure given represents the mean of results obtained in four years 1871, 1874, 1875, and 1876.

TABLE II.

Description of Herbage.	Without Manure.	Mixed Mineral Manure.		Mean.
		Including Potash.	Excluding Potash.	
	Plot 3.	Plot 7.	Plot 8.	
NITROGEN—per cent. in Dry substance.				
Gramineous	1·40	1·32	1·35	1·36
Leguminous	2·64	2·65	2·92	2·73
Miscellaneous	1·63	1·45	1·64	1·57
TOTAL Mineral Matter (pure ash)—per cent. in Dry substance.				
Gramineous	6·40	7·02	6·86	6·76
Leguminous	8·07	8·63	7·79	8·16
Miscellaneous	9·24	10·76	10·27	10·09

It may be stated that, in the absence of nitrogenous manuring, the produce of each of the three plots contained much lower than average proportions of gramineous herbage; that of plot 3 (without manure), and of plot 8 (without potash) containing fair, but not large proportions of leguminous, but very large amounts of miscellaneous herbage; whilst that of plot 7 on the other hand, with full mineral manure including potash, contained the lowest percentage of gramineous, very much more leguminous, but much less miscellaneous herbage, than the others. The hay of all three would be fairly matured; but that of plot 8 less so than either of the others.

It is seen that the percentage of nitrogen in the dry substance was the lowest in that of the gramineous produce, higher in that of the miscellaneous, and on the average about twice as high in the leguminous as in the gramineous herbage. Of total mineral matter (pure ash), the percentage in the dry substance is the lowest in the gramineous, higher in the leguminous, and much higher in the miscellaneous herbage.

These general distinctions are useful to bear in mind, and they are of themselves sufficient to show how variable must be the chemical composition of the mixed produce, with variation in botanical composition.

The question with which we have to deal is, however, a much more complicated one than that of the mere proportions of the gramineous, the leguminous, and the miscellaneous herbage, in the mixed produce, or the percentages they respectively contain of nitrogen and of total mineral matter. But, before going into further detail, it will be well to refer in general terms, by way of example, to some well established facts, the appreciation of which will serve to prepare the way for an adequate conception and interpretation of the detailed facts themselves.

Thus, the application of nitrogenous manures to the complex produce of grass-land greatly increases the proportion, and the actual amount, of the gramineous herbage. If the supply of nitrogen be excessive in relation to the amount of the mineral or ash-constituents at the same time available, the herbage will be characteristically leafy, most probably of an abnormally dark green colour, and will contain an abnormally high percentage of nitrogen in its dry substance. If, on the other hand, there be, at the same time, a plentiful supply of mineral constituents, including potash, the herbage will develop much stem, and show much tendency to flowering, seeding, and ripening. Under these latter conditions, more carbon is assimilated in proportion to the nitrogen taken up, and the percentage of nitrogen in the dry substance will accordingly be much lower; and this will be the case notwithstanding that as much, or even more nitrogen, may have been taken up over a given area. Again, if the herbage be characteristically leafy, the result of a deficiency of available potash, the proportion of lime in the ash will be the greater, and that of potash the less; whilst conversely, if the produce be characteristically stemmy, the proportion of potash in the ash will be correspondingly high. In other words, coincidently with what may be distinguished as the merely vegetative stages of

growth, lime will relatively be more prominent in the ash than potash, whilst with stemminess and tendency to maturation, potash will be relatively more prominent than lime. It is obvious, therefore, that although each of the three main descriptions of herbage under consideration may have its characteristic composition as distinguished from the others, yet each may be subject to a wide range of difference according to the character of the development.

State of existing knowledge as to the function of the mineral or ash-constituents in vegetation.

Before entering into any more detail as to the chemical composition of the separated gramineous, separated leguminous, and separated miscellaneous herbage, or upon the consideration of the chemical composition of the mixed produce of about 20 plots over 40 or more seasons, which will involve the discussion of the results of more than 200 complete analyses of the ashes of the separated or the mixed produce, it will be well to summarise briefly the state of existing knowledge as to the rôle or function in vegetation of the individual mineral constituents found in the ashes of plants.

Thus, VINES ('Lectures on the Physiology of Plants,' 1886) says—

"With regard to the elements constituting the ash . . . their absorption by the plant depends essentially upon the activity of its metabolism."

. . . "*sulphur* is a constituent of the proteid substances, and this is practically all that is known as to its use in the economy" . . . "sulphates occur in solution in the cell-sap of organs in which metabolism is actively proceeding, and are doubtless formed in connection with the decomposition of proteid."

"*Phosphorus* is taken up by plants in the form of phosphates. It enters into the composition of some of the substances which constitute the organised parts of plants," . . . . It also—"bears an important relation to some of their metabolic processes. Phosphates are always to be found in relation with living protoplasm, but the exact significance of this fact is unknown.

"*Potassium* is absorbed in a variety of compounds, such as the sulphate, phosphate, chloride, and probably also the silicate. . . . Like phosphorus, potassium is always found in relation with living protoplasm; in fact it appears from DE SAUSSURE'S observations that the amount of potash in an organ affords an indication of the metabolic activity of the organ." . . . "The function with which potassium appears to be especially connected in plants containing chlorophyll, is that of the formation of organic substance." . . . "It is, however, not known what is the precise significance of potassium in relation to the formation of organic substance." . . . "That potassium bears some important relation to the formation and to the storing-up of carbohydrates is shown by the fact that the organs in which these processes are taking place, such as leaves, seeds, tubers, etc., are those parts of plants which are richest in this element."

Calcium.—"The precise use of calcium to plants is unknown. It cannot be replaced in the food of plants which contain chlorophyll by any other metal." . . . "It is especially abundant in the leaves of green plants" . . . "calcium occurs commonly in the cell-wall, and it is well known that it forms compounds with proteids. It is therefore possible that it contributes to the building up of the tissues in the form of organic compounds. Calcium very commonly occurs in the cells of plants in the form of crystals of the carbonate or oxalate, and it is possibly one of the important functions of calcium to form insoluble salts with acids which are of no further use in, and are even injurious to the plant."

Magnesium.—"Very little is known as to its use. Its distribution appears to be tolerably uniform."

Iron.— . . . "Iron has been detected in the most different plants and in the various parts of plants, either in the cell-contents or in the cell-wall, but it has been found to be essential only to those plants which contain chlorophyll." . . . "Iron plays, therefore, an important part in the formation of the green colouring-matter, chlorophyll, but . . . it does not enter into its chemical composition. It doubtless affects, in some way, the processes in the cell which lead to the formation of the chlorophyll, and also of the chlorophyll-corpuscles," . . .

Sodium.—"This element, one of the most widely distributed, is, as might be expected, never absent from the ash of plants, and in some cases, especially in maritime plants, it is present in considerable quantity. It was thought that, possibly it might serve as a substitute for potassium in the nutrition of the plant, but this has not been found to be the case."

Chlorine.—"Chlorine also is a very constant constituent of the ash of plants, but it does not appear to be essential to their nutrition." . . . "It seems probable, therefore, that chlorine has no direct influence upon the metabolism of plants, but only an indirect one, the chloride being the compound of potassium which is most advantageous to the plant."

Silicon.—"Silicon is absorbed in the form of soluble silicates, or possibly as soluble silicic acid. It principally occurs in plants in the cell-wall." . . . "Inasmuch as silica is always present in the ash, and frequently in very large quantity, it was thought that silicon must be essential to the nutrition of plants."

The following quotations are from the English edition of SACHS' 'Physiology of Plants,' translated by Professor MARSHALL WARD, and published in 1887.

Silica.— . . . "We may regard it as certain that this substance is superfluous for the chemical processes of nutrition, as well as for the molecular movements connected with growth." He quotes experiments in which he brought maize plants to vigorous and complete development with the help of nutritive solutions to which not even a trace of silica was added. But he says—"Although it is thus shown that this substance, widely distributed in plants, is superfluous for the purposes of nutrition and growth, it would be going too far to regard it as superfluous also in every other connection."

Iron.—"We know that the small traces of iron salts are of the greatest importance in the process of nutrition of ordinary green plants, since without iron the proper instrument of nutrition, chlorophyll, is not formed."

"With this, however, our definite knowledge of the physiological significance of the nutritive substances mentioned is practically exhausted; we know, to put it shortly, nothing certain as to the parts played by potassium, calcium, magnesium, and phosphorus, in assimilation and metabolism. With respect to sulphur, we know at least that it forms an indispensable constituent in the chemical composition of proteids, and is, therefore, necessary for the building up of protoplasm. With respect to the others, however, only so much is established, that they are absolutely indispensable for assimilation—that is for the production of organic plant substance; . . . The salts of these elements, therefore, certainly take part in the chemical processes which occur during the formation of organic plant-substance from inorganic material, though we do not know what part they play in it." Again . . . "In the first place, every part of a plant, every cell-wall, even the youngest, and likewise the protoplasm, and even starch grains, leave an ash behind after combustion; and from their general occurrence it may be concluded that certain constituents of the ash at least are indispensable for the chemical composition, or for the molecular structure of the cell-walls and protoplasm. A second fact worth noting is the abundance of ash-constituents in the green assimilating leaves: this is at once explained when we know that these constituents are continually being carried by the transpiration current to the leaves, and are retained in them on the evaporation of the water, and when we observe that no assimilation occurs in their absence, as experiments on vegetation demonstrate."

"Finally, ash-analyses show that the quantitative composition—that is, the relative richness in potassium, calcium, magnesium, and phosphorus—changes according to the nature and the age of the organ of a

plant. Ripe seeds, for example, usually contain relatively much potassium, magnesium, and phosphorus. Since, however, it is not possible to bring the facts so far known as to the composition of the ash, into immediate connection with definite physiological functions, we will now leave this subject for the present."

ADOLPH MAYER, in his 'Lehrbuch der Agricultur Chemie,' 3rd Edition 1886, discusses the known or supposed rôle of the individual ash-constituents of plants; and his conclusions may be briefly summarised as follows:—

Sulphur.—The proteids contain sulphur to the extent of 1 per cent. or less; many plants contain other sulphur compounds; for example, the sharp essential oils of mustard seed, horse-radish, etc.; but it is still unknown whether sulphur has any other function in the vegetable organism, though many plants contain sulphates.

Phosphorus.—The proteids in plants frequently contain small amounts of phosphorus or phosphates, which cannot be completely removed from them without their losing some of their properties. Indeed, there is reason to believe that phosphorus has a part in the production of proteids.

Silica.—Many plants, which under ordinary conditions contain much silica, may be grown without any supply of it. Maize, for example, the ash of which generally contains 20 per cent. of silica, may under artificial conditions of growth yield an ash containing only 1 per cent. Experimental evidence seems to show that silica does not play any important part in the processes of plant life.

Chlorine.—It would seem that chlorine is not, like sulphur and phosphorus, a necessary ash-constituent. It may, however, be useful under some circumstances; as some plants, buckwheat for example, seem not to thrive without it; and some vegetation experiments seem to show that it aids the solution of starch grains, and so favours the circulation of starch in the plant.

Potassium.—Just as the proteids are always accompanied by phosphates, so the carbohydrates are always accompanied by potash. The so-called "potash plants" are those in which large amounts of carbohydrates are produced; but it is still unknown in what way potassium salts bring about the production, circulation, and deposition of carbohydrates.

Calcium.—Calcium salts seem to take part in the transport of starch, and the conversion of available organic substance into "building material." Calcium is chiefly found in the leaves.

Magnesium.—Magnesium seems to follow the proteids in their way through the plant; and it is accumulated in large amounts in the fruit of the cereals, from the time that they begin to flower.

Iron.—Iron is necessary for the formation of chlorophyll; but its action is not understood. It is probable that it is present in the plant as a constituent of an organic compound.

It should be added that A. MAYER published a new edition, of his 'Lehrbuch' in 1895—but there is substantially no change from the above.

Some reference should here be made to the work and to the observations of the late Professor EMIL VON WOLFF, who, under the title of 'Aschen-Analysen' published two large quarto volumes in which he collected together the results of most published ash-analyses, up to the date of 1880.

In the letterpress of his work he does not discuss the physiological significance of the different constituents; but he summarises and generalises the facts in their bearing on the distribution of them, in different crops, and the different parts of crops. Thus, he calls attention to the average percentages of the constituents in the ash, and in the dry matter, of various crops, and parts of crops.

In reference to WOLFF'S conclusions, it may be said that, although there must necessarily be some general accordance between the indications of the results he deals with, and those we have ourselves obtained, yet there are considerable discrepancies also. This is only what would be expected when it is considered that his are the individual and average results of large numbers of analyses, by many different analysts, of the ashes of produce grown under very widely differing conditions of soil, climate, and other circumstances; whilst those obtained in the course of our own investigations relate to the produce of one description of soil, though with very widely differing conditions as to manuring, and also with widely varying conditions as to season.

The foregoing summary will show the extent, or rather the limit, of existing knowledge as to the precise office of the individual constituents found in plant-ashes. It is not unreasonable to expect, that the detailed study and discussion of the actual and comparative composition of the ashes of between 200 and 300 vegetable products, of which both the conditions and the results of growth are accurately known, should throw some light on the subject; and we think it will be admitted that the results do afford important evidence on some points of much interest.

The conditions under which Carbonic acid is determined in plant-ashes, and the results obtained.

It should here be premised, that the late Professor EMIL VON WOLFF—to whom chemists are indebted for the collation and publication in a collective form, of the results of more than 4000 analyses of the ashes of a great variety of vegetable products, grown under different conditions as above referred to—in calculating the percentage composition of the "pure ash," excluded not only the sand and the charcoal, but also the carbonic acid; and this plan has generally been adopted by others. Any special importance of carbonic acid in plant-ashes has therefore been generally ignored. We think, however, that it will be recognised as we proceed, that the presence, and the amount, of carbonic acid associated with the fixed constituents in plant-ashes, is a point of considerable significance. Hence, it is desirable that something should be said in this place, as to the existence, and as to the determination, of carbonic acid in plant-ashes.

The amount of carbonic acid is, of course, of interest as affording some indication of the amount of organic acids in combination with the fixed bases, existing in the produce submitted to incineration. There can, however, be no question, that in the process of incineration a considerable amount of carbonic acid is frequently expelled, more or less according to the description of the produce. Doubtless, too, such expulsion is greatly augmented in the presence of silica. Hence, in an ash re-ignited at low red heat before weighing out for analysis, so as to exclude water and secure fixity of composition upon which to calculate the results—the totals then providing a good check on the work—the amount of carbonic acid determined under such conditions will be lower, and sometimes much lower, than in what may be termed the *natural ash*. Indeed, the actual amount so determined is of comparatively little further interest than to provide a check by the totals, on the accuracy of the analysis.

Accordingly, after much preliminary experiment by Mr. RICHTER on the point, it was finally decided, that in most ashes (including the large number involved in the present investigation), a second carbonic acid determination should be made, after saturation of the ash with a solution of ammonium-carbonate, and drying at a fixed temperature (125–130° C.). In this way, a greater or less amount of carbonic acid is restored. But, in many cases, calculation shows that there is not enough restored to convert the whole of the fixed bases into neutral salts. Therefore, this second determination

of carbonic acid, though much nearer the truth than the first, cannot be taken as adequately representing the amount of organic acid destroyed in the incineration.

Owing, however, to the varying basicity of phosphoric acid, and also to other circumstances, the estimation of the amount of carbonic acid in the natural ash by calculation of the amount required to convert the bases into neutral salts, is liable to considerable irregularity, and could not safely be generally adopted. But if the whole of the phosphoric acid found be reckoned as tribasic, the amount of carbonic acid indicated by such calculation might, perhaps, at any rate be assumed to be the minimum. Still, a figure so obtained could not appropriately be embodied in a table of otherwise experimentally-determined results. We adopt, therefore, in the tables, in all cases, the carbonic acid determined after treatment of the ash with ammonium-carbonate. That is to say, excluding sand and charcoal, and the carbonic acid determined in the ash as analysed, and inserting instead, that found after treatment by ammonium-carbonate, the whole of the constituents are then re-calculated to 100. Obviously, if the increase in the amount of carbonic acid is greater than the amount of sand and charcoal excluded, the "100" represents an amount of total *pure ash* higher than that of the *crude ash.* At the foot of each Appendix Table of analyses, however, will be found, for comparison, the amount of carbonic acid as determined in the ash as analysed; the amount obtained after treatment with ammonium-carbonate; and also the amount as calculated to be required to convert (with the other acids), the whole of the bases into neutral salts, assuming in all cases that the phosphoric acid is tribasic.

In reference to the above points it should be stated that the late Professor R. W. BUNSEN proposed a new method of ash-analysis, and of control of the accuracy of the results. The ash was to be re-saturated with carbonic acid, and the constituents to be determined separately in the watery extract and in the residue. The phosphoric acid found in the watery extract was to be reckoned as bibasic, and the remainder as tribasic. Finally, if the analysis was correct, calculation should show that the acids and bases found existed in the proportions to form neutral salts ('Zeits. Anal. Chem.,' 1870, p. 283). It will, however, be seen as we proceed, that the proposed method of control would be inapplicable in the case of the ashes of some important crops.

Composition of the ashes of the separated Gramineous, separated Leguminous, and separated "Miscellaneous" Herbage.

Let us now turn to the results of the analyses of the ashes of the separated gramineous, leguminous, and miscellaneous herbage. These are given in a form convenient for study and comparison in Table III., pp. 156–157. As the heading of the table shows, the analyses relate to the ashes of the produce (first crops), respectively of six differently manured plots; four of them (plots 2, 3, 7, and 8) receiving no nitrogenous manure, but, the remaining two (plots 19 and 20) having both mineral and a moderate amount of nitrogenous manure, in the one case as nitrate of soda, and in the other as nitrate of potash. It will be further seen that, in the case of each of

the four plots without nitrogenous manure, the ash is a mixture of that of the separated herbage of each of four years, 1871, 1874, 1875, and 1876, which is made proportionally to the amount of ash in the produce per acre each year. In the case of each of the two plots with nitrogenous manure, the ashes represent the separated herbage of two years only, 1875 and 1876. There are also given, for comparison, in the last column, results relating to second crops, grown in 1875, each ash analysed being a proportionally mixed sample of that of three differently manured plots, all without nitrogenous manure. Lastly, it will be seen that the table shows the percentage of each constituent, in the ash of the gramineous, the leguminous, and the miscellaneous herbage, respectively.

Looking first to the column showing the mean results for the six different descriptions of manuring, and confining attention to some points of chief significance, it will be seen that of *lime* the ash of the gramineous herbage contained on the average only 9·76 per cent., whilst that of the miscellaneous herbage contained 19·08 per cent., or nearly twice as much, and that of the leguminous 25·26 per cent., or more than two-and-a-half times as much as the ash of the gramineous herbage.

Of *potash*, on the other hand, the ash of the gramineous herbage contained by far the most—29·93 per cent. against 23·91 in that of the miscellaneous, and only 20·44 per cent. in that of the leguminous herbage.

Of *phosphoric acid*—the ash of the gramineous herbage shows an average of 7·15, that of the miscellaneous of 6·35, and that of the leguminous of 6·18 per cent.

Of *sulphuric acid*—the gramineous ashes show an average of 6·42, the miscellaneous of 4·75, and the leguminous of much less, or only 2·83 per cent.

Of *chlorine*—the ash of the gramineous herbage again shows the highest average percentage—7·42, that of the miscellaneous coming next, with 4·96 per cent., and that of the leguminous again the least—only 3·26 per cent.

Of *carbonic acid*, however, whilst with the large amount of silica the ash of the gramineous herbage contains an average of only 7·87 per cent., that of the miscellaneous, with much less silica, contains 23·61 per cent., and that of the leguminous herbage, with scarcely any silica, an average of 29·44 per cent. of carbonic acid. The actual average percentage of *silica* in the different descriptions of ash is—in the gramineous 25·25, in the miscellaneous 5·67, but in the leguminous ash only 1·69 per cent.

The main points of distinction are then—that the ash of the gramineous herbage contains much silica, comparatively little lime, much potash, and but little carbonic acid; that of the leguminous herbage, on the other hand, contains scarcely any silica, the most lime, relatively little potash, little sulphuric acid or chlorine, but a very large amount of carbonic acid—assumed to represent a proportionally large amount of more complex organic acid destroyed in the incineration. The ash of the miscellaneous herbage again, shows not much silica, comparatively medium amounts of lime and potash, but a considerable amount of carbonic acid.

TABLE III.—Percentage composition of the "*pure ash*," of the separated Gramineous, separated Leguminous, and separated "Miscellaneous" Herbage.

Description of Herbage.	Mixed year samples—First crops. 4 years, 1871, '74, '75 and '76. Farmyard Manure 8 years, 1856–'63, Unmanured since. Plot 2.	Without Manure. Plot 3.	Mixed Mineral Manure, including Potash. Plot 7.	Mixed Min. Man., with Potash 1856–'61, without Potash since.* Plot 8.	2 years 1875 and '76. 43 lb. N., as Nitrate of Soda; Superphos., and Sulph. Potash. Plot 19.	43 lb. N., as Nitrate of Potash; and Superphosphate. Plot 20.	Mean	Second Crops, 1875. Mixed Plot sample, Plots 2, 3, and 7.
LIME.								
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Gramineous .	9·30	11·85	11·05	10·71	7·63	8·04	9·76	9·14
Leguminous .	30·29	28·54	21·36	26·39	21·44	23·52	25·26	25·88
Miscellaneous .	21·17	23·89	13·50	18·43	18·42	19·05	19·08	18·77
Mean . .	20·25	21·43	15·30	18·51	15·83	16·87	18·03	17·93
MAGNESIA.								
Gramineous .	3·63	3·76	2·68	3·46	2·44	2·40	3·06	3·17
Leguminous .	7·53	5·51	4·71	6·85	3·77	3·64	5·33	5·25
Miscellaneous .	4·96	5·32	3·14	4·96	3·25	2·46	4·02	4·25
Mean . .	5·37	4·86	3·51	5·09	3·15	2·83	4·14	4·22
POTASH.								
Gramineous .	22·47	22·56	35·71	25·42	35·55	37·90	29·93	28·62
Leguminous .	12·63	13·81	31·31	11·18	26·36	27·35	20·44	21·34
Miscellaneous .	15·87	16·13	34·91	16·00	28·78	31·77	23·91	22·54
Mean . .	16·99	17·50	33·98	17·53	30·23	32·34	24·76	24·17
SODA.								
Gramineous .	5·04	4·10	0·39	5·30	3·34	1·16	3·22	1·99
Leguminous .	4·44	7·48	0·64	9·64	6·16	3·59	5·33	4·06
Miscellaneous .	11·69	8·76	2·70	13·37	5·69	2·88	7·51	7·56
Mean . .	7·06	6·78	1·24	9·44	5·06	2·54	5·35	4·54
PHOSPHORIC ACID.								
Gramineous .	5·74	4·79	7·66	9·67	7·71	7·32	7·15	6·62
Leguminous .	6·02	4·81	6·74	8·59	5·79	5·15	6·18	5·44
Miscellaneous .	4·99	3·96	7·57	8·02	7·38	6·19	6·35	5·30
Mean . .	5·58	4·52	7·32	8·76	6·96	6·22	6·56	5·79

* Also sawdust (but practically without effect) first 7 years 1856–62.

TABLE III (continued).—Percentage composition of the "*pure ash,*" of the separated Gramineous, separated Leguminous, and separated "Miscellaneous" Herbage.

Description of Herbage.	Mixed year samples—First crops. 4 years, 1871, '74, '75 and '76. Farmyard Manure 8 years, 1856–'63, Unmanured since. Plot 2.	Without Manure. Plot 3.	Mixed Mineral Manure, including Potash. Plot 7.	Mixed Min. Man., with Potash 1856–'61, without Potash since.* Plot 8.	2 years 1875 and '76. 43 lb. N., as Nitrate of Soda; Superphos., and Sulph. Potash. Plot 19.	43 lb. N., as Nitrate of Potash; and Superphosphate. Plot 20.	Mean.	Second Crops, 1875. Mixed Plot sample, Plots 2, 3, and 7.
SULPHURIC ACID.								
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Gramineous .	5·73	5·46	6·96	8·44	6·39	5·53	6·42	8·41
Leguminous .	2·82	2·60	3·27	3·92	2·25	2·10	2·83	2·63
Miscellaneous .	4·93	4·94	5·27	4·76	4·51	4·08	4·75	5·70
Mean . .	4·49	4·33	5·17	5·71	4·38	3·90	4·66	5·58
CHLORINE.								
Gramineous .	6·81	7·18	6·45	6·17	9·53	8·39	7·42	4·94
Leguminous .	3·35	4·46	2·41	3·48	3·12	2·72	3·26	2·94
Miscellaneous .	5·53	5·99	4·95	6·21	3·70	3·40	4·96	3·87
Mean . .	5·23	5·88	4·60	5·29	5·45	4·84	5·21	3·92
CARBONIC ACID (2nd determination†).								
Gramineous .	5·11	7·82	11·32	5·46	7·97	9·53	7·87	6·90
Leguminous .	30·80	30·90	27·85	27·29	29·62	30·19	29·44	30·18
Miscellaneous .	24·99	26·28	19·39	20·93	24·99	25·09	23·61	22·53
Mean . .	20·30	21·67	19·52	17·89	20·86	21·60	20·31	19·87
SILICA.								
Gramineous .	36·56	32·36	17·33	24·79	20·28	20·16	25·25	29·91
Leguminous .	1·92	1·87	1·32	2·10	1·44	1·51	1·69	1·92
Miscellaneous .	6·14	4·93	8·35	7·42	2·83	4·35	5·67	9·39
Mean . .	14·87	13·05	9·00	11·44	8·18	8·67	10·87	13·74

* Also sawdust (but practically without effect) first 7 years 1856–62.

† After treatment with a solution of ammonium-carbonate.

So much for the comparative average composition of the ashes of the three typically different descriptions of herbage. Attention must now be directed to the great variations in the composition of the ash of one and the same description of herbage under the influence of different manures; that is to say, with different amounts of the several constituents at the command of the plants, and, with this, different conditions of development of the herbage accordingly.

With regard to the selection of plots for the separation of the three descriptions of herbage, and the determination of their composition, it may be explained that, as the object was to compare, or to contrast, the composition of the different descriptions, it was essential to select for separation and analysis the produce of plots where all would be fairly represented; which, from what has been said, would obviously not be the case where nitrogenous and mineral manures were used together, the result of which would be a too exclusively gramineous produce, with comparatively little miscellaneous, and less still of leguminous herbage. In fact, it is only in the cases in which no, or not much, nitrogenous manure is used, that a fair amount of the miscellaneous or leguminous herbage is found. Reference to Table I. (pp. 144–145) will strikingly illustrate this.

In the first place it is to be borne in mind that neither of the four plots—2, 3, 7 or 8—received any artificial nitrogenous manure; whilst the two remaining plots —19 and 20—each received, besides mineral manures, fair amounts of nitrogenous manure, in the one case as nitrate of soda, and in the other as nitrate of potash. Under the different conditions of the four plots without nitrogenous manure, plot 2 (unmanured after farmyard manure), gave produce containing nearly 80 per cent. of gramineous, only little leguminous, and only a moderate proportion of miscellaneous herbage. The produce of plot 3 (continuously unmanured), contained less than 70 per cent., that of plot 7 (with mineral manure including potash) less than 60 per cent., but that of plot 8 (with mineral manure excluding potash) between 70 and 80 per cent. of gramineous herbage. Again, the produce of plots 3 and 8 gave comparatively small amounts of leguminous, but large amounts of miscellaneous herbage; whilst that of plot 7, with the lowest percentage of gramineous herbage, contained an unusually large proportion of leguminous, and only a moderate amount of miscellaneous herbage. In contrast with these botanical characters of the produce of the plots without nitrogenous manure, that of plots 19 and 20, with nitrogenous as well as mineral manure, gave more than 80 per cent. of gramineous herbage, only small amounts of leguminous, and comparatively small amounts of miscellaneous herbage.

Bearing in mind these great differences in the botanical composition of the herbage of the six plots, and the fact that, with the difference of manuring, and difference in the proportions of the herbage, there will also be wide differences in the character of the development of the plants, as to leafiness, stemminess, maturing tendency, etc., the differences in the chemical composition of each of the three descriptions of separated herbage according to the manuring, as shown in the table, become intelligible.

With these observations, it will suffice to call attention to a few typical differences of composition, which the Table (III) brings to view.

First as to the variation in the composition of the ashes of the gramineous herbage grown under the six different conditions of manuring. The table shows that the percentage of *lime* ranged from 7·63 and 8·04 in the ashes of the produce of plots 19 and 20 with mineral manure and nitrate of soda or nitrate of potash, to 11·85 in that of plot 3 continuously unmanured. In fact, it was lower in the ash of the gramineous herbage grown with mineral and nitrogenous manure, giving a predominantly luxuriant gramineous and stemmy produce, than in the case of either of the other plots. On the other hand, with the liberal supply of potash, and this character of herbage, the percentage of *potash* in the ash was very high (35·55 and 37·90). It was also very high (35·71) in the gramineous herbage of plot 7, with mineral manure including potash but without nitrogenous manure; conditions under which, though the gramineous herbage would not be at all luxuriant, but stunted, it would nevertheless be stemmy. In the other three cases (2, 3, and 8) without potash supply, the percentage of it in the ash was much lower (22·47, 22·56, and 25·42). In the case of the same three plots the percentages of magnesia were very nearly identical, as also were those of soda.

Of *phosphoric acid*, the percentage in the gramineous ashes is much the higher in that from plots 7, 8, 19 and 20, where phosphatic manure was annually applied, than in that from plots 2 and 3 where it was not. The percentages of *sulphuric acid*, and of *chlorine*, range within narrower limits than those of phosphoric acid. But the characteristic constituent of gramineous ashes—silica, ranges in percentage from only 17·33 in that of the herbage of plot 7 where none is supplied, and the botanical composition, and the character of development, of the herbage, is determined by the liberal provision of potash and phosphoric acid, to 32·36 on the continuously unmanured plot 3, and to 36·56 per cent. on plot 2 where large amounts had been supplied in farmyard manure some years previously. Lastly in regard to the composition of the ash of the gramineous herbage, it is to be observed, that there was the lowest amount of carbonic acid in the ash of the produce of plot 2 (5·11), with the highest percentage of silica, and the highest percentage in the ash of plot 7 (11·32), with the lowest amount of silica. There can be no doubt that the amount of organic acid represented after incineration by carbonic acid, depends largely on the botanical composition of the herbage, and on the character of its development; neither can there be any doubt that, as already explained, the amount of carbonic acid found varies greatly according to the character of the ash in other respects, and especially on the amount of silica it contains.

The results relating to the *leguminous ashes* afford perhaps even more striking illustrations of the influence of supply on the composition of the produce; the differences being, of course, largely dependent on the character of the development of the plants which the differences of supply have induced.

Thus, with deficient supply of potash on plots 2, 3, and 8, there were comparatively small proportions of leguminous herbage in the mixed produce; whereas on plot 7, with abundant supply of potash, but without nitrogen to force gramineous growth, there was an unusually high percentage of leguminous herbage developed. On the other hand, on plots 19 and 20, with a liberal supply of potash, but also of nitrogenous manure favouring gramineous growth, there was the lowest percentage of leguminous herbage. Obviously too, with such wide differences in the predominance of such herbage according to the manures, there would be considerable difference in the character of development of the plants.

Assuming that, within limits, a relative predominance of lime in the ash is specially associated with what may be distinguished as the more purely vegetative, and that of potash more with the maturing tendencies of growth, the results in the table relating to the composition of the ashes of the leguminous herbage are of interest. With the greatest proportion of luxuriant gramineous, and the smallest proportion of leguminous herbage, in the produce of plots 19 and 20, we have comparatively low percentages of lime in the leguminous ashes (21·44 and 23·52); but we have the lowest percentage of it in the ash of the produce of plot 7 (21·36), where there was the highest proportion of leguminous herbage under the influence of liberal supply of potash. The highest percentages of lime in the leguminous herbage are in the produce of plots 2, 3, and 8 (30·29, 28·54, and 26·39), without any supply of potash by manure.

Turning to the percentages of *potash* in the leguminous ashes, they range from 11·18, 12·63, and 13·81 in the produce of plots 8, 2, and 3, without potash supply and comparatively low proportions of leguminous herbage, to 31·31 or between two and three times as much, on plot 7 with potash supplied, and the highest proportion of leguminous herbage. On the other hand, the percentage of potash is high in the ash of the leguminous herbage of plots 19 and 20, with potash supply (26·36 and 27·35), but with the lowest proportions of leguminous herbage.

The percentages of *phosphoric acid* in the leguminous ashes do not vary in so great a degree as do those of lime or of potash; but where no nitrogenous manure was used, and the proportion of such herbage in the produce was the greater, the percentage of phosphoric acid in the ash was higher with than without supply by manure —being 6·74, and 8·59 with, and 6·02 and 4·81 without supply by manure. The percentage in the ash of the leguminous herbage was, however, low in the produce of the plots 19 and 20 (5·79 and 5·15) with nitrogenous manure and predominantly luxuriant gramineous herbage.

Lastly, there is a very small percentage of *silica* in the ash of the leguminous herbage; but there is, on the other hand, a higher percentage of *carbonic acid* than in the ash of either of the other descriptions of herbage, and the range in the amount of it is comparatively small, the lowest percentage being 27·29, and the highest 30·90.

Turning to the variations in the composition of the ash of the complex "*miscellaneous herbage*," it is to be borne in mind, that the Orders, genera, and species, brought into prominence, as well as the character of development of the plants, will vary very greatly under the different conditions of manuring, and the coincident variations in the competition among the different descriptions of herbage; so that the differences in composition will be referrible to more complex conditions than in the case of either the gramineous or the leguminous herbage. Hence, the figures the more clearly illustrate the influence of the supplies within the soil on the results of growth.

The range of variation in the composition of the ash of such complex miscellaneous herbage is indeed very considerable. Thus, first taking the four plots without nitrogenous manure, the percentage of *lime* varies from 13·50 in the produce of plot 7 with a liberal supply of potash, to 23·89 without manure (plot 3); whilst the *potash* on the other hand varies from 34·91 per cent. in the ash of the produce of plot 7, with a liberal supply of it, to only 16·13 without manure. Then, the ash of the miscellaneous herbage of plot 8 with mineral manure excluding potash, and plots 19 and 20 with mineral manure including potash, but with nitrogenous manure also—all three plots yielding prominently gramineous herbage, the first leafy and immature, but the others stemmy and more matured—all show about the same percentage of lime—18·43, 18·42, and 19·05; but the produce of plot 8 without potash in manure, and with characteristically leafy herbage, shows only 16·0 per cent. of potash, and that of plots 19 and 20 with potash supplied and a stemmy gramineous produce, 28·78, and 31·77 per cent. Of *soda*, the percentage in the ash of the miscellaneous herbage was the lowest in that of plot 7 (2·70) with liberal potash supply, although soda was also applied, and the highest in that of plot 8 with deficient potash supply (13·37). It was also comparatively high on the potash-exhausted plots 2 and 3 (11·69 and 8·76). Again it is also much higher in the produce of plot 19 with nitrate of soda (5·69), than on plot 20 with nitrate of potash (2·88).

Of *phosphoric acid*, the ash of the miscellaneous herbage of plots 7, 8, 19 and 20, where it was liberally supplied, contained—7·57, 8·02, 7·38 and 6·19 per cent., or considerably more than that of plots 2 and 3—4·99 and 3·96, where it was not supplied, and the soil was much exhausted. Of the less functionally important constituents, the percentage of *sulphuric acid* is the highest in the ash of the miscellaneous herbage of plot 7 (5·27), where there was the most supplied; but it is lower and fairly uniform, in the case of the other plots. Of *chlorine* again, the percentage is the highest on the otherwise more exhausted plots 2, 3, and 8, but the lowest on plots 19 and 20 with both mineral and nitrogenous manure, and the lowest percentages of miscellaneous herbage. Then, the percentages of *silica* in the ashes of the miscellaneous herbage are comparatively small, but very variable; and where it is the highest (8·35), the *carbonic acid* is the lowest (19·39); and in the other cases the percentage of carbonic acid is in the main in inverse order to that of the silica. Thus, with 7·42 silica (plot 8), there is 20·93 per cent. of carbonic acid; with 6·14

silica (plot 2) 24·99 carbonic acid; with 4·93 silica (plot 3) 26·28 carbonic acid; with 4·35 silica (plot 20) 25·09 carbonic acid; and with 2·83 silica (plot 19) 24·99 carbonic acid.

Lastly, as illustrative of the influence of the supply of potash on the composition of each of the three descriptions of herbage, it is seen that, comparing the composition of the ash of the produce of plot 7 with, and of plot 8 without, potash supply, the percentage of potash is, in that of the gramineous herbage 35·71 with, and 25·42 without potash; in that of the leguminous herbage 31·31 with, and 11·18 without potash; whilst in that of the miscellaneous herbage it is 34·91 with, and 16·00 without potash supply. Then under the same conditions as to supply of potash, soda being applied to both plots, the percentages of soda in the ashes were, in the gramineous herbage 0·39 with potash supply, and 5·30 without; in the leguminous 0·64 with, and 9·64 without; and in the miscellaneous 2·70 with, and 13·37 without potash supply.

In conclusion with regard to the figures in Table III. (pp. 156–157) a comparison with one another of the last two columns will show, that the general character of the ash of each description of herbage is, with few exceptions, much the same in the first and in the second crops. It will also be observed that the differences are the greater in the case of the less functionally important constituents, such as soda and chlorine, for example. It will be seen in a subsequent Section, however, that in the case of each of the three descriptions of herbage, the percentage of nitrogen is much higher in the dry substance of the produce of the second crops, that is of the autumn growth, than in that of the first crops; and not only is the percentage of nitrogen higher, but the proportion of the total nitrogen which is in the albuminoid or best food-condition, is the higher in the second or autumn crops. Nevertheless, the higher percentage of nitrogen cannot of itself be taken as evidence of higher feeding quality. It is, in fact, rather an indication of deficient carbon-assimilation in relation to the nitrogen taken up; that is deficient formation of the non-nitrogenous substances.

The foregoing results illustrate very clearly the characteristic differences in the composition of the three descriptions of herbage, and also the range of variation in the composition of each, dependent on the supplies within the soil, the species developed, and the character of their development, accordingly. They at the same time bring prominently to view, the intricacy of the subject of the influence of variations in manure, and variations of season, on the composition of a complex and still growing, more or less succulent, and unripened crop. They will, however, afford material aid in the interpretation of the differences in the composition of the mixed herbage ot grass-land, when we come to consider the results relating to it in more detail.

Dependence of the chemical composition of various crops, on the character, and the stage, of their growth.

We will now refer to some other results, which will afford evidence of a more definite kind, in regard to some of the questions that will arise. The first of these to

TABLE IV.—Composition of the Bean-plant at 6 different periods of growth. Per cent.; per 1000 dry matter; and per acre.

	Whole Plants.						Leaf.	Stalk.	Leaf and Stalk, Total.
	May 26, Before blooming.	June 17, Bloom on.	July 8, Bloom off bottom, on top.	July 29, Bloom off, Pod on.	Aug. 30, Green Pod just turning.	Sept. 8, Seed fairly ripe.	June 17 Bloom on.		
COMPOSITION of the Plants—Per cent.									
Dry Matter	10·46	9·85	13·29	17·91	25·27	40·58	...	...	...
Per cent. in Dry Matter { Nitrogen	4·46	3·25	2·91	2·69	2·86	2·88	...	...	...
Per cent. in Dry Matter { Pure ash	11·27	9·22	7·91	6·64	5·49	4·96	...	...	...
COMPOSITION of the Pure Ash—Per cent.									
Ferric oxide and Alumina	1·27	1·18	0·86	0·56	1·16	1·46	0·92	1·14	...
Lime	17·19	17·27	19·64	22·80	21·64	19·50	26·46	7·18	...
Magnesia	2·85	2·99	3·19	3·23	3·42	3·86	3·43	2·24	...
Potash	33·99	32·91	31·12	28·40	29·87	30·24	22·40	42·80	...
Soda	4·37	5·12	4·44	3·06	3·03	4·50	4·44	6·25	...
Phosphoric acid	8·39	8·13	8·01	7·75	11·11	11·98	7·60	7·27	...
Sulphuric acid	2·13	3·15	2·70	2·95	3·41	3·78	2·69	2·84	...
Chlorine	4·73	3·62	3·12	2·68	2·65	2·91	2·05	5·13	...
Carbonic acid*	24·45	25·35	26·72	28·24	23·59	21·88	29·05	24·76	...
Silica	1·70	1·10	0·90	0·94	0·71	0·55	1·42	1·55	...
Total	101·07	100·82	100·70	100·61	100·59	100·66	100·46	101·16	...
Deduct O = Cl	1·07	0·82	0·70	0·61	0·59	0·66	0 46	1·16	...
Total	100·00	100·00	100·00	100·00	100·00	100·00	100 00	100·00	...
PER 1000 Dry Matter.									
Nitrogen	44·6	32·5	29·1	26·9	28·6	28·8	...	...	...
Pure ash	112·7	92·2	79·1	66·4	54·9	49·6	...	...	...
Lime	19·39	15·92	15·53	15·14	11·88	9·67	...	...	...
Magnesia	3·21	2·75	2·53	2·14	1·88	1·91	...	...	...
Potash	38·33	30·33	24·62	18·85	16·40	14·99	...	...	..
Soda	4·91	4·72	3·52	2·03	1·66	2·23	...	...	...
Phosphoric acid	9·45	7·49	6·33	5·15	6·10	5·94	...	...	...
Sulphuric acid	2·39	2·90	2·13	1·96	1·87	1·87	...	...	...
Chlorine	5·32	3·34	2·46	1·78	1·45	1·45	...	...	...
Carbonic acid*	27·58	23·36	21·13	18·75	12·95	10·85	...	...	...
PER acre, lb.									
Nitrogen	13·1	31·2	72·2	114·2	119·9	129·6	...	...	...
Pure ash	33·0	88·4	196·3	281·9	230·2	223·1	45·3	40·3	85·6
Lime	5·68	15·27	38·55	64·27	49·82	43·49	11·98	2 90	14·88
Magnesia	0·94	2·64	6·27	9·09	7·87	8·61	1·55	0·90	2·45
Potash	11·23	29·09	61·11	80·02	68·77	67·46	10·14	17·24	27·38
Soda	1·44	4·53	8·73	8·60	6·97	10·04	2·01	2·52	4·53
Phosphoric acid	2·77	7·18	15·72	21·86	25·59	26·72	3·44	2·93	6·37
Sulphuric acid	0·70	2·78	5·29	8·33	7·84	8·42	1·22	1·14	2·36
Chlorine	1·56	3·20	6·10	7·57	6·10	6·51	0·92	2·07	2·99
Carbonic acid*	8·08	22·40	52·45	79·61	54·31	48·80	13·15	9·98	23·13

* Second determination—after treatment with a solution of ammonium-carbonate.

call attention to will illustrate more clearly the connection between the character and stage of growth of a plant, and the mineral or ash-constituents found in the product, and they relate to some experiments made at Rothamsted many years ago. We then, at six different periods during the growth of a bean-crop, cut the plants from a given area, so that the produce per acre at the different periods could be calculated; and took careful samples for analysis. In these, the dry matter, the nitrogen, and the ash, were determined; and subsequently complete analyses of the ashes were made, the details of which have, however, never before been published; though some of the results have been referred to in summary form. The results are recorded in Table IV. p. 163.

In the upper or first division of the table are given—the percentages of dry matter, of nitrogen in the dry matter, also of pure ash in the dry matter, that is excluding the sand and charcoal and the carbonic acid found in the ash as analysed, but including the carbonic acid restored by treatment of the ash with ammonium-carbonate.

In the second division is given the percentage composition of the "pure ash" as above described. It may be stated that the amount of carbonic acid so determined in such an ash, containing as it does scarcely any silica, is sufficient or more than sufficient, with the phosphoric acid, the sulphuric acid, and the chlorine, to convert the whole of the bases into neutral salts, assuming the phosphoric acid to be tribasic.

The third division shows the amounts of nitrogen, of total ash (pure), and of each ash-constituent, in 1000 parts of dry matter.

Lastly, the fourth division shows the amounts of nitrogen, of pure ash, and of the more important mineral or ash-constituents, in the produce per acre.

Turning to the results in the table, it is seen that the percentage of lime in the ash increased from 17·19 before blooming, to 22·80 when the bloom was off and the pod was forming. The percentage of potash in the ash was 33·99, or about twice as much as that of the lime, before blooming; but it diminished slightly, instead of increasing as did that of the lime, up to the time of pod-formation, and afterwards slightly increased. Thus, although lime was very prominent during growth, potash was more so.

But, when we look, not to the percentage of lime and of potash respectively, in the ashes at the different periods of development of the plant, but to the actual amounts of them taken up and retained over a given area, as shown in the quantities of each per acre in the growing crop at the different periods, it is found that, up to the end of what may be designated the vegetative as distinguished from the maturing stages, the amount of lime gained in proportion to that of potash, but afterwards declined in proportion to the potash. Thus, whilst in the earlier stages of development the amount of lime in the growing crop was only about or little more than half as much as that of the potash, its relation gradually increased until on June 29 when the bloom was off and the pod formed, there were four-fifths as much lime as potash. At

that time the actual amount of lime per acre in the growing crop was 64·27 lb. and that of potash 80·02 lb.; after which both declined, and on September 8 when the seed was ripe, only 43·49 lb. of lime, and 67·46 lb. of potash were found in it. The potash, therefore, decreased in a less proportion than the lime during the maturing stages.

It might be supposed that there was some error in these estimates of the amounts of the crop and of its constituents over a given area, and they admittedly involve some difficulty and uncertainty; as for example, the possibility of loss by fallen leaves, etc. But the fact that the phosphoric acid, which would probably for the most part exist in a less soluble and less migratory condition, is shown by the figures to increase gradually in amount per acre from the first period to the last, tends to confirm the contrary results relating to the lime and the potash; and, assuming them to be correct, the supposition is, that a quantity of surplus lime and potash had been accumulated in, or excreted by, the roots.

In connection with the difference in the relative amounts of lime and of potash, at the different stages of development, the results given in the last two columns of the division of the table relating to the percentages, are of much interest. They show the percentages of the different constituents in the ash of the leaf and of the stalk separately, on June 17 when the bloom was on, and when, therefore, the maturing tendencies were beginning to attain ascendency. It is seen that at this time, whilst the leaf-ash contained 26·46 per cent. of lime, the stalk-ash contained only 7·18 per cent.; on the other hand, whilst the leaf-ash contained only 22·40 per cent. of potash, the stalk-ash contained 42·80 per cent., or nearly twice as much. There would seem, therefore, in the relative amounts of lime and of potash, both at the different periods of growth, and in the different parts of the plant at a given stage of development, to be evidence of more direct connection of the lime with the assimilating or more purely vegetative stages of development, and of the more prominent connection of the potash with the elaboration of the more final and the more fixed products of the plant.

It has been already explained, that in the case of an ash containing so little silica as that of the bean plant, the amount of carbonic acid restored by the treatment of the ash with ammonium-carbonate, brings up the amount approximately to what is required to form, with the other acids, a "neutral" or assumed *natural ash*. At any rate, the amounts of it recorded are of considerable significance. Thus, referring to the division of the table showing the percentage composition of the ashes, it is seen that, at the first period, the carbonic acid amounted to 24·45 per cent., and that it gradually increased to 28·24 per cent. on July 29, when the pod was formed, but afterwards decreased to 21·88 per cent. The calculated amounts of carbonic acid in the ash of the crops per acre were, 8·08 lb. at the first period, but 79·61 lb. when the pod was formed; from which time it diminished to 48·8 when the seed was ripe. In fact, lime, potash, and carbonic acid, all increased in actual amount in the crop up to the period of pod-formation, and they all diminished afterwards.

The general result is, that the ash of this highly nitrogenous leguminous crop, grown to seed-formation, contained, at each stage, about 50 per cent. of lime and potash taken together; the potash always predominating, but the lime increasing relatively to the potash up to the period of pod-formation, but afterwards declining in relative amount. Further, the ash contained an average of about 25 per cent. of carbonic acid; more up to the time of pod-formation, but less afterwards. That is to say, the ash, on the average, consisted of about 75 per cent. of lime, potash, and carbonic acid; whilst at the time of pod-formation it contained nearly 80 per cent.

Bearing in mind the foregoing facts, we will now turn from results relating to the ripened, corn-yielding, leguminous bean crop, to some relating to the still more highly nitrogenous, but unripened clover crops; the amount of nitrogen collected by which depends on a much more protracted, merely vegetative character of growth. Thus, when the crop is grown for fodder, it is not allowed to ripen, but is cut when it reaches the blooming stage, so inducing re-growth, and an extension of the more specially assimilative or vegetative stages. The analytical results bearing on the subject have not hitherto been published and are brought together in Table V., p. 167.

In the upper division are given the results relating to the first crops; in the middle those for the second crops; and in the lower division those for the third crops. The particulars recorded are—the percentages of nitrogen, and of pure ash, in the dry matter; and the percentage composition of the pure ash. As the table shows, the crops were grown under three different conditions as to manuring. The first and second crops were, in each case, grown in two separate seasons, 1850 and 1874; but the third crops in 1874 only.

A glance at the figures showing the percentage composition of these clover-ashes, and a comparison of them with those relating to the ripened bean plant, will at once bring to view the prominent points of similarity and of difference, in the mineral composition of these two leguminous crops—the one grown for the production of seed, and the other developing throughout much more of assimilative and vegetative, and much less of reproductive and maturing tendencies of growth. The average results given in the last three columns show, that lime, potash, and carbonic acid are still the most prominent constituents; indeed in the clover-ashes they amount together to from about 80 to nearly 85 per cent. of the total. But, whilst in the ash of the corn-yielding bean-crop there was about one-and-a-half time as much potash as lime, there is in that of the merely vegetating unripened clover, a range of from nearly twice to even three times as much lime as potash. The more direct connection of the lime than of the potash with the assimilative or merely vegetative stages of development, is here again, therefore, strikingly brought to view. It is, indeed, further confirmed by the difference in the composition of the ash of the first, the second, and the third crops of clover. Thus, in the ash of the first and third crops, the proportion of lime to potash is greater than in that of the second crops, which

TABLE V.—Percentage Composition of 1st, 2nd, and 3rd, crops of Red Clover, grown by different manures, and in different seasons.

	Unmanured.		Superphosphate.		Mixed Manure including Potash.		Averages of the two years.		
	1850.	1874.	1850.	1874.	1850.	1874.	Un-manured.	Super-phosphate.	Mixed Manure.
COMPOSITION of the First crops, per cent.									
Per cent. in Dry Matter { Nitrogen	2·72	2·13	2·68	2·48	2·68	2·37	2·57	2·59	2·51
Per cent. in Dry Matter { Pure ash	10·55	9·03	9·91	9·35	10·14	8·89	10·15	9·66	9·45
COMPOSITION of the Pure ash of the First crops, per cent.									
Ferric oxide	1·03	1·10	0·94	0·87	0·50	0·69	1·05	0·91	0·60
Lime	37·37	35·68	36·54	38·38	35·27	31·40	36·98	37·33	33·28
Magnesia	5·10	4·67	5·02	5·29	5·01	4·90	5·00	5·14	4·96
Potash	13·10	14·04	14·36	10·77	15·93	20·22	13·32	12·82	18·14
Soda	0·58	1·08	0·55	0·98	0·68	0·63	0·69	0·73	0·65
Phosphoric acid	3·75	2·82	3·69	3·62	4·52	4·68	3·53	3·66	4·60
Sulphuric acid	1·82	2·93	1·88	2·34	2·12	2·55	2·08	2·08	2·34
Chlorine	2·26	3·34	2·19	2·55	3·13	2·88	2·51	2·34	3·00
Carbonic acid*	34·96	32·50	34·78	34·25	33·05	31·64	34·39	34·55	32·32
Silica	0·54	2·59	0·54	1·53	0·50	1·06	1·02	0·97	0·79
Total	100·51	100·75	100·49	100·58	100·71	100·65	100·57	100·53	100·68
Deduct O = Cl.	0·51	0·75	0·49	0·58	0·71	0·65	0·57	0·53	0·68
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
COMPOSITION of the Second crops, per cent.									
Per cent. in Dry Matter { Nitrogen	2·92	2·74	2·88	3·14	2·79	3·04	2·86	2·98	2·89
Per cent. in Dry Matter { Pure ash	8·15	8·45	8·31	9·08	8·02	9·28	8·25	8·60	8·56
COMPOSITION of the Pure ash of the Second crops, per cent.									
Ferric oxide	0·35	0·90	0·35	0·69	0·38	0·69	0·55	0·49	0·52
Lime	32·89	31·44	32·21	32·69	32·70	29·25	32·37	32·41	31·10
Magnesia	5·69	6·18	6·35	6·41	6·26	5·50	5·87	6·37	5·91
Potash	17·62	18·49	17·57	16·51	16·93	21·99	17·93	17·14	19·27
Soda	0·58	0·50	0·62	0·80	0·69	0·52	0·55	0·69	0·61
Phosphoric acid	5·74	4·62	5·65	6·03	5·95	6·60	5·34	5·80	6·25
Sulphuric acid	2·91	3·07	2·83	2·83	3·05	3·35	2·97	2·83	3·19
Chlorine	2·78	3·85	3·15	3·74	4·09	3·17	3·16	3·39	3·67
Carbonic acid*	31·73	30·47	31·61	30·37	30·47	28·92	31·28	31·11	29·75
Silica	0·34	1·35	0·37	0·77	0·41	0·73	0·70	0·53	0·56
Total	100·63	100·87	100·71	100·84	100·93	100·72	100·72	100·76	100·83
Deduct O = Cl.	0·63	0·87	0·71	0·84	0·93	0·72	0·72	0·76	0·83
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
COMPOSITION of the Third crops (1874 only), per cent.									
Per cent. in Dry Matter { Nitrogen	...	3·34	...	3·53	...	3·36			
Per cent. in Dry Matter { Pure ash	...	10·62	...	10·70	...	10·67			
COMPOSITION of the Pure ash of the Third crops (1874 only), per cent.									
Ferric oxide	...	2·01	...	0·84	...	1·19			
Lime	...	35·96	...	36·83	...	32·03			
Magnesia	...	5·43	...	5·69	...	5·36			
Potash	...	12·30	...	12·25	...	17·73			
Soda	...	0·78	...	0·73	...	0·81			
Phosphoric acid	...	3·94	...	5·42	...	5·69			
Sulphuric acid	...	2·78	...	3·21	...	3·47			
Chlorine	...	3·35	...	3·82	...	3·86			
Carbonic acid*	...	31·32	...	30·89	...	29·20			
Silica	...	2·89	...	1·19	...	1·53			
Total	...	100·76	...	100·87	...	100·87			
Deduct O = Cl.	...	0·76	...	0·87	...	0·87			
Total	...	100·00	...	100·00	...	100·00			

* Second determination—after treatment with a solution of ammonium-carbonate.

would develop at a period of the year when the seed-forming tendency would be the greater.

Again, whilst in the ash of the ripened bean-plant there was only 21·88 per cent. of carbonic acid, there was in that of each of the clover crops about, or more than, 30 per cent.; in that of the first, or most luxuriant crops, from 32·34 to 34·52 per cent., but in that of the subsequent crops somewhat less.

Leaving out of view, for the purposes of our present argument, the importance of other ash-constituents—phosphoric acid, sulphuric acid, magnesia, etc.:—in connection with the formation or the migration of the nitrogenous compounds of plants, we will here limit our illustrations to an endeavour to throw some light on the significance of the fact of the great predominance of lime, potash, and carbonic acid, in the ashes of the specially nitrogen-accumulating leguminous crops, and the greater predominance of lime and of carbonic acid in the ashes of the clover with its more continuous vegetative growth, and greater accumulation of nitrogen over a given area, than in those of the ripened bean crop.

It is obvious that, so far as the nitrogen of plants is taken up as the nitrate of a fixed base, that base, if it do not pass back into the roots, will remain in the above-ground parts of the plant, most probably in combination with an organic acid, which will be converted into carbonic acid on incineration, and be found as such in the ash, if not expelled by an excess of fixed acid, or by silica. With a view to the elucidation of some of the points herein involved, it will be of interest to consider the relation of the nitrogen and certain of the ash-constituents, in the different parts, and in the total produce, of some typical crops; representing respectively, different natural Orders of plants.

Accordingly, there are brought together in Table VI., p. 169, results relating to the grain, to the straw, and to the total produce of wheat; to the "roots," to the leaves, and to the total produce of Swedish turnips; to the corn, to the straw, and to the total produce of beans; and lastly, to the first, second, and third crops of clover. In the upper division of the table are given, the percentages of nitrogen, and of pure ash, in the dry matter of each product; also the percentage composition of the pure ash in each case. In the second division the amounts of nitrogen, and of each of the more important ash-constituents, in the produce per acre are given. Lastly, in the third division, there are shown the amounts of each important ash-constituent for 100 of nitrogen in the separate portions, and in the total produce of each crop.

It may be further explained, that all the figures given in the Table VI., relate to crops grown in the rotation experiments at Rothamsted, and that they represent actual analytical results in each case. It may be added that each of the four crops—wheat, Swedish turnips, beans, and red clover—were grown on the plot receiving at the commencement of each rotation a mixed mineral and nitrogenous manure, so that the conditions of growth were fairly normal and uniform. In the case of the wheat,

TABLE VI.—Percentage Composition of different Crops; also constituents per acre, and ash-constituents for 100 Nitrogen in the crops.

	Crops grown in Rotation.											
	Wheat.			Swedish Turnips.			Beans.			Red Clover.		
	Grain.	Straw.	Total.	Root.	Leaf.	Total.	Corn.	Straw.	Total.	1st crop, (Average of 1850 and 1874.)	2nd crop, (Average of 1850 and 1874.)	3rd crop, (1874 only.)
COMPOSITION of the Crops—per cent.												
Per cent. in Dry Matter } Nitrogen	1·72	0·43	0·88	2·20	4·01	2·41	4·32	0·94	2·41	2·51	2·89	3·36
Per cent. in Dry Matter } Pure Ash	1·89	6·26	4·74	5·92	11·66	6·60	3·27	5·80	4·70	9·45	8·56	10·67
COMPOSITION of the Pure Ash—per cent.												
Ferric oxide	0·66	0·32	0·37	0·45	2·87	0·96	0·48	1·54	1·22	0·60	0·52	1·19
Lime	3·23	4·59	4·41	10·73	23·58	13·42	5·60	28·39	21·49	33·28	31·10	32·03
Magnesia	11·13	1·67	2·98	2·99	1·60	2·70	6·61	3·12	4·18	4·96	5·91	5·36
Potash	32·66	13·57	16·21	38·88	26·69	36·33	40·58	8·07	17·91	18·14	19·27	17·73
Soda	0·16	0·43	0·39	4·96	1·67	4·27	2·12	14·57	10·80	0·65	0·61	0·81
Phosphoric acid	49·99	2·51	9·09	9·68	8·22	9·38	30·69	2·31	10·90	4·60	6·25	5·69
Sulphuric acid	1·44	2·75	2·56	12·74	10·90	12·36	6·35	3·30	4·22	2·34	3·19	3·47
Chlorine	0·05	1·69	1·46	2·56	10·30	4·18	2·43	2·49	2·48	3·00	3·67	3·83
Carbonic acid*	...	2·64	2·27	17·08	13·49	16·33	5·28	33·68	25·09	32·32	29·75	29·20
Silica	0·69	70·22	60·58	0·52	3·01	1·04	0·41	3·08	2·27	0·79	0·56	1·53
CONSTITUENTS per acre, lb.												
Nitrogen	28·3	13·4	41·7	75·5	18·5	94·0	49·6	14·0	63·6	103·3	56·0	5·4
Lime	1·01	8·91	9·92	21·84	12·69	34·53	2·10	24·50	26·60	129·41	51·46	5·51
Magnesia	3·47	3·25	6·72	6·08	0·86	6·94	2·47	2·70	5·17	19·26	9·78	0·92
Potash	10·19	26·32	36·51	79·12	14·36	93·48	15·20	6·96	22·16	70·55	31·89	3·05
Soda	0·05	0·83	0·88	10·09	0·90	10·99	0·79	12·58	13·37	2·54	1·01	0·14
Phosphoric acid	15·60	4·87	20·47	19·70	4·42	24·12	11·49	1·99	13·48	17·90	10·34	0·98
Sulphuric acid	0·45	5·33	5·78	25·93	5·86	31·79	2·38	2·85	5·23	9·11	5·28	0·60
Chlorine	0·01	3·28	3·29	5·21	5·54	10·75	0·91	2·15	3·06	11·67	6·06	0·66
Carbonic acid*	...	5·12	5·12	34·76	7·26	42·02	1·98	29·07	31·05	125·71	49·23	5·02
Silica	0·22	136·22	136·44	1·06	1·62	2·68	0·16	2·65	2·81	3·07	0·92	0·26
ASH-CONSTITUENTS for 100 Nitrogen in the Crops.												
Lime	3·56	66·52	23·79	28·92	68·57	36·72	4·23	174·36	41·82	125·27	91·97	102·02
Magnesia	12·27	24·22	16·11	8·06	4·65	7·39	4·99	19·18	8·13	18·65	17·47	17·07
Potash	36·01	196·40	87·55	104·80	77·62	99·45	30·67	49·55	34·84	68·30	56·99	56·48
Soda	0·18	6·20	2·12	13·37	4·85	11·69	1·60	89·50	21·02	2·46	1·81	2·57
Phosphoric acid	55·11	36·35	49·08	26·09	23·90	25·66	23·19	14·19	21·20	17·33	18·48	18·13
Sulphuric acid	1·59	39·75	13·85	34·34	31·70	33·82	4·80	20·28	8·22	8·82	9·43	11·06
Chlorine	0·05	24·47	7·90	6·90	29·96	11·44	1·84	15·31	4·82	11·30	10·83	12·30
Carbonic acid*	...	38·22	12·28	46·04	39·23	44·70	3·99	206·87	48·81	121·69	87·98	93·00
Silica	0·76	1016·57	327·18	1·40	8·75	2·85	0·31	18·91	4·42	2·97	1·65	4·87

* Second determination—after treatment with a solution of ammonium-carbonate.

the results are the means of those obtained on "mixed year samples," made proportionally to the amount of ash yielded per acre in the crops each year, for the four years 1851, 1855, 1859, and 1863, and for the four years 1867, 1871, 1875, and 1879, and they represent, therefore, the averages for eight years. The results for the Swedish turnips are those obtained on "mixed year samples" proportionally made as above, for the three years 1864, 1872, and 1876. The results for the beans are the means of those obtained in the same way, for the three years 1854, 1858, and 1862, and for the three years 1866, 1870, and 1878. Lastly, as described at the head of the columns, the results for the first and second crops of red clover are the averages of those obtained for the crops of 1850 and 1874; but those for the third crop are for 1874 only.

The results relating to *wheat.* There is reason to believe that most, if not the whole, of the nitrogen of the wheat-crop is taken up as nitrate; but the amount of nitrogen which it assimilates over a given area is small compared with that stored up in other crops, such as root-crops, and leguminous crops. Further, carbonic acid is seldom found in wheat-grain-ash, and there is but little in the straw-ash. Indeed, calculating the whole of the phosphoric acid as tribasic, wheat-grain-ashes show more than one-and-a-half time as much fixed acid as base; and even calculating the whole of the phosphoric acid as bibasic there would still be an excess of acid. On the other hand, wheat-straw-ashes calculated in the same way, show a considerable excess of base, even when the whole of the phosphoric acid is reckoned as tribasic; but they seldom contain less, and sometimes more, than 60 per cent. of silica. So far, however, as the relation of the mineral composition to the nitrogen taken up by the plant is concerned, it is obviously not the relation found between the ash-constituents and the nitrogen of the grain or of the straw separately, that has to be considered, but that indicated by the results obtained on the whole crop. Thus, taking the ash of the total produce (grain and straw together in proper proportions), and reckoning the whole of the phosphoric acid to be tribasic, there remains a considerable excess of base. Assuming, therefore, that there have been organic acid salts formed with the bases liberated from the nitrate taken up, part may have been eliminated into the roots, or excreted by them from the plant; and from what remains, the carbonic acid formed may have been expelled in the incineration by the excess of fixed acid in the grain-ash, and by silica in the straw-ash. It may be added, that by treating the ash with a solution of ammonium-carbonate and drying at 130° C., very little carbonic acid is taken up by the grain-ash with its excess of fixed acid, and not much more by the straw-ash with its excess of fixed base, but large amount of silica. Under these circumstances the amount of carbonic acid in the ash of the total crop is very small; and on the assumption that the nitrogen had been taken up as nitrate of a fixed base, which afterwards became combined with organic acid, represented by carbonic acid after incineration, the amount of it found would only be sufficient to account for a very small proportion of the total nitrogen taken up.

Then as to the so-called *root-crops.* Swedish turnips, for example, assimilate

much more nitrogen over a given area than the cereal crops, and unlike them they are removed from the land whilst still in a growing and unripened condition. For their nitrogen they depend largely at any rate on nitrates in the soil; and they contain larger actual amounts of both lime and potash than the cereals; much more potash than lime in the more definite product—the root, but a much higher proportion of lime to potash in the more specially assimilating and residue-accumulating organs—the leaves. The ash of both root and leaf also contains a considerable amount of carbonic acid, as determined after treatment with ammonium-carbonate. In the case of the root-ash, which contains very little silica, the amount of the so-determined carbonic acid approximately brings the whole of the bases to neutral salts, if the phosphoric acid be reckoned as tribasic; indeed it leaves a small excess of acid, presumably indicating, therefore, that the whole of the phosphoric acid was not tribasic. In the case of the leaf-ash, with rather more silica, similar calculation shows that the restored carbonic acid is not quite sufficient to bring the whole of the bases to neutral salts. The amount of carbonic acid in the total crop (roots and leaves), for 100 of nitrogen taken up, is very much greater than in the case of the wheat crop; indeed it would represent a much larger, but still only a comparatively small, proportion, of the total nitrogen of the crop, assuming it to have been taken up as nitrate, and the base combined with organic acid represented by carbonic acid after incineration.

Then as to the *leguminous crops.* Under equal soil-conditions they assimilate very much more nitrogen over a given area than the cereals, and some of them very much more than root-crops. There is no doubt that, independently of the nitrogen they acquire as the result of the fixation of free nitrogen within their root-nodules, due to the symbiotic action of the nodule-microbes and the host plant, they derive at any rate much nitrogen from nitrates in the soil and subsoil. Thus, experiments at Rothamsted have shown that various Leguminosæ (*Trifolium repens*, *Vicia sativa*, *Melilotus leucantha*, and *Medicago sativa*) take up nitrogen as nitrates from the soil and subsoil, in very various degrees, and to different depths, according to the range and character of their roots; the shallow and weakly rooting, *Trifolium repens*, for example, only utilising the supplies of the upper depths, whilst the deep and powerfully rooting *Medicago sativa* practically exhausted the subsoil of its nitrates down to the depth of twelve times 9 = 108 inches. Then again, white clover grown in a pot in a glass house in sterilised sand, with the ash of the plant, gave practically no growth beyond that due to the nitrogen in the seed sown; whilst pots of similarly prepared sand and ash as soil, microbe-seeded from a rich garden soil, showed very luxuriant growth, much gain of nitrogen, and many nodules were found on the roots. Further, a similarly prepared pot manured with a solution of nitrate of lime, also gave luxuriant growth, but there were no nodules on the roots. Notwithstanding, however, that the evidence is conclusive that leguminous plants do take up nitrogen as nitrates within the soil and subsoil, it is well known that such plants are not, and that clover especially is not, characteristically benefited by the direct application of

nitrate of soda when the crops are grown in the ordinary course of agriculture. When, however, nitrate is applied directly as manure, it will rapidly percolate, chiefly as nitrate of soda or nitrate of lime, unaccompanied by the other necessary mineral constituents in an available condition; whereas, in the case of nitric acid being gradually formed as a result of action on the organic nitrogen of the soil and subsoil, it will probably be associated with other constituents, liberated, and so rendered available at the same time within the range of the growing roots.

Let us now turn to the results in Table VI. (p. 169) referring to the leguminous crops—beans and clover; and first—to those relating to the seed-yielding bean crop. Comparison of the figures in the columns relating to the corn and straw separately, though of much independent interest, have obviously no direct bearing on the question of the relation of the ash-constituents to that of the nitrogen taken up. Thus in the corn is accumulated about three-fourths of the total nitrogen of the crop, a large amount of potash and a large proportion of the phosphoric acid of the crop; but a very small proportion of the lime, the magnesia, the soda, the sulphuric acid, the chlorine, or the carbonic acid. Then again, the straw in which is accumulated all residues which have not passed into the roots, or through them from the plant altogether, contains less than a fourth of the total nitrogen of the crop, but a very large proportion of some of the ash-constituents, especially lime, soda, and carbonic acid; and hence the relation of the ash-constituents to the nitrogen, in either the corn or the straw separately, would be misleading, so far as the question now under discussion is concerned. Turning to the column relating to the total crop, corn and straw together, it is seen that the amount of each of the bases, lime, magnesia, potash, and soda, for 100 of nitrogen taken up, is much higher than in the more fixed product—the corn; whilst lime predominates over potash. There is also, with great excess of fixed base to fixed acid, a large amount of carbonic acid—four times as much in relation to 100 nitrogen as in the case of the ripened cereal crop, with the large excess of fixed acid in the grain ash, and the large amount of silica in the straw ash. There is even more carbonic acid for 100 nitrogen than in the unripened and succulent root-crop, with its higher amount of nitrogen per acre. Still the amount of carbonic acid would correspond to only about one-third of the total nitrogen of the crop, part of which would, however, undoubtedly be due to fixation.

Lastly, referring to the three columns relating respectively, to the first, second, and third, crops of the immature, continuously growing, and very high nitrogen-yielding, clover, it is seen that for 100 of nitrogen taken up, the amounts, especially of lime and of carbonic acid, are very much higher than in the case of the total produce of either of the other crops. There is also a large amount of potash, and of magnesia, but very little soda. There are, however, comparatively small, but fairly uniform amounts of phosphoric acid, of sulphuric acid, and of chlorine, which, taken together, leave a very great deficiency of fixed acid to fixed base. But there are, on the other hand, very much larger amounts of carbonic acid than in the case of the other crops.

Further, there is more lime for 100 of nitrogen in the bean crop, than in either the wheat or the root-crop. But there are more than twice, and even three times, as much lime for 100 of nitrogen in the clover crops, as in the bean crop. In the case of neither of the four descriptions of crop is there, however, as much lime as would be required, if the whole of the nitrogen had been taken up as nitrate of lime, and the whole of the lime were found in the ash; and the probability is that part of the nitrogen taken up as nitric acid was as the nitrate of some other base.

It is obvious that—so far as the nitrogen had been taken up as the nitrate of a fixed base, which when liberated was combined with organic acid, the whole remaining in the above-ground parts of the plant, and the organic acid represented after incineration by carbonic acid—there should be 22 parts of carbonic acid in the ash for 14 parts of nitrogen in the crop. In other words, under such conditions, 100 of nitrogen in the crop should be represented by 157 of carbonic acid in the ash. But, the Table shows that, not even in either of the clover crops did the amount of carbonic acid found correspond to as much as 157 for 100 of nitrogen in the crop. In the first place, there can be no doubt, that more or less of the nitrogen of the clover would be due to fixation. Then, again, there is the question whether organic acid may have been formed otherwise than in combination with the bases liberated from the nitrate taken up.

The actual quantities of nitrogen per acre in the clover were—in the first crops 103·3 lb., in the second 56·0 lb., in the third 5·4 lb., or in all 164·7 lb.; and assuming the action to have been as above supposed, the amounts of carbonic acid found in the ashes would represent—in the first crop 80 lb., in the second 31·33 lb., and in the third 3·19 lb., of nitrogen taken up as nitrate; and these quantities would correspond, in the case of the first crops to 77·4, of the second to 55·9, and of the third to 59·1 per cent., of the total nitrogen of the crops. The figures would thus indicate that a much larger actual quantity, as well as a higher proportion, of the total nitrogen of the first than of either the second or the third crops had been taken up as nitrate. They would further indicate that, of the total nitrogen of the 3 crops (164·7 lb.), approximately 114·5 lb. were due to nitrate taken up, leaving, therefore, 50·2 lb. to be accounted for by fixation. It is true that the chemical actions involved in fixation are not yet understood; but, in the meantime, the foregoing general indications are of much interest.

It is at any rate perfectly clear, that there are very characteristic differences in the composition of the ashes of different crops, according to the amounts of nitrogen they assimilate. The Leguminosæ, for example, yield comparatively large amounts of nitrogen over a given area, part of which is due to fixation, but they certainly also take up much as nitrate; and the results show, that the greater the amount of nitrogen they assimilate the more is the ash characterised by containing fixed base (especially lime), in combination with carbonic acid; presumably representing organic acid in the vegetable substance before incineration.

It would seem, therefore, to be established by the results adduced, that independently of any specially physiological function of the bases, such as that of potash in connection with the formation of carbohydrates for example, their office is prominently also that of *carriers of nitric acid;* and that when the nitrogen has been assimilated, the base is left as a residue in combination with organic acid, which is represented more or less completely, by carbonic acid in the ash.

It would further seem that, besides the greater or less amount of nitrogen which leguminous plants acquire as the result of fixation within their root-nodules, they have the power of assimilating more nitrogen over a given area in other ways than other crops; probably owing to their ability, by virtue of the character and range of their roots, to gather up more nitrogen from the soil and subsoil in the form of nitrates.

In connection with these points it is further of interest to observe, that existing knowledge—as to the condition in which combined nitrogen is found in soil-waters, as to the action of nitrates used as manures, as to the presence of nitrates in still-growing plants, and as to the connection between the nitrogen assimilated and the composition of the ash as has been illustrated—points to the conclusion that, at any rate a large amount of the nitrogen of the chlorophyllous vegetation on the earth's surface is derived from nitrates; whilst, so far as this is the case, the *raison d'être* of much of the fixed base found in the ashes of plants would seem to be clearly indicated.

The composition of the crops of the Mixed Herbage of the first 20 years—1856–1875.

We have, in the foregoing, endeavoured to throw some light on the connection between the growth of crops and their mineral composition, by reference to results relating to the separated gramineous, the separated leguminous, and the separated miscellaneous herbage, of the mixed produce of grass-land, grown without manure and by different manures. To obtain more definite evidence illustrating the connection between character and stage of growth, and the composition of the products—especially the ash-composition—we have given and discussed results relating to the bean plant, taken at successive periods of growth; and also to the first, second, and third, crops of red clover. Lastly, in further illustration, we have compared the composition, both as to nitrogen and ash-constituents, and the relation of the two, of crops of three different natural Orders—the Gramineæ, the Cruciferæ, and the Leguminosæ. Of the Gramineæ, the ripened wheat crop was taken as the example; of the Cruciferæ, Swedish turnips; and of the Leguminosæ, beans were taken as the ripened crop, and red clover as an example of an unripened and continuously growing crop. These various results, with the conclusions arrived at on the study of them, will be found to afford material aid in the interpretation of the differences in the composition of the *mixed herbage of grass-land*, which we have now to consider in detail.

TABLE VII.—Percentage Composition of the Mixed Herbage of Grass-land (First (

	Group 1. Plots without Manure, or with Farmyard Manure.							Group 2. Plots with Nitrogenous Manures alone.			
	Unmanured continuously.	Farmyard Manure 8 years 1856–63; Unmanured since.			Farmyard Manure and 43 lb. N. as Amm.-salts 8 years 1856–63; 43 lb. N. as Amm.-salts alone since.			Amm.-salts = 86 lb. Nitrogen.	Nitrate Soda = 86 lb. Nitrogen, 1858 and since.	Nitrate Soda = 43 lb. Nitrogen, 1858 and since.	Mi Min M nu in clud Pot
		8 years 1856–1863.	10 years 1864–1873.	18 years 1856–1873.	8 years 1856–1863.	10 years 1864–1873.	18 years 1856–1873.				
	Plot 3.	Plot 2.			Plot 1.			Plot 5.	Plot 15.	Plot 17.	Plo
NITRO											
Per cent. in Dry Matter: Nitrogen	1·66	1·46	1·31	1·38	1·50	1·44	1·46	2·16	1·89	1·74	1·
Per cent. in Dry Matter: Crude Ash	6·82	8·29	6·62	7·36	8·11	6·24	7·07	5·85	6·54	6·79	7·
Per cent. in Dry Matter: Pure Ash	7·03	8·42	6·79	7·52	8·20	6·34	7·17	6·02	6·84	7·02	8·
Ferric oxide	0·58	0·47	0·46	0·47	0·56	0·54	0·55	0·57	0·60	0·78	0
Manganese oxide	0·54	0·22	0·34	0·29	0·31	0·65	0·50	1·42	0·33	0·59	0
Lime	17·26	10·52	12·11	11·40	11·34	12·64	12·06	14·03	10·48	12·03	11
Magnesia	4·58	3·18	4·21	3·75	3·30	4·88	4·18	6·17	4·22	4·23	3
Potash	19·10	30·74	24·31	27·16	29·68	21·39	25·07	17·74	14·53	16·93	34
Soda	6·88	2·82	5·03	4·05	3·97	8·42	6·45	8·48	18·02	13·14	1
Phosphoric acid	5·24	6·92	6·67	6·78	6·67	6·96	6·83	6·39	5·33	5·12	7
Sulphuric acid	5·98	4·76	4·69	4·72	4·99	5·81	5·44	8·25	5·52	5·73	6
Chlorine	5·97	8·98	5·14	6·85	12·94	11·85	12·33	11·15	6·45	6·53	5
Carbonic acid†	12·15	8·12	10·06	9·20	5·62	5·49	5·55	6·20	14·58	13·10	13·
Silica	23·06	25·29	28·13	26·87	23·54	24·05	23·82	22·11	21·40	23·30	15·
Total	101·34	102·02	101·15	101·54	102·92	102·68	102·78	102·51	101·46	101·48	101·
Deduct O = Cl.	1·34	2·02	1·15	1·54	2·92	2·68	2·78	2·51	1·46	1·48	1·
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·

* Also sawdust (but practically without effect) first 7 y

First Crops), grown by different Manures; including the Composition of the *Pure Ash*—Mea[n]

Total Period, 18 years, 1856–1873.

...us	Group 3. Plots with Mineral Manures alone.					Group 4. Plots with Nitrogenous and Mineral Manures together							
...ate ...da ... lb. ...ro- ...n, ...58 ...d ...ce.	Mixed Mineral Manure, including Potash.	Sawdust alone, 1856–1858.	Superphosphate of lime alone, 1859 and since.	Mixed Mineral Manure including Potash, 1856–1861. *	Mixed Mineral Manure excluding Potash, 1862 and since. *	Mixed Mineral Manure, and Amm.-salts = 86 lb. Nitrogen.	Mixed Min. Man., and Amm.-salts = 86 lb. Nitrogen, and Wheat Straw.	Mixed Min. Man., and Amm.-salts = 129 lb. Nitrogen, 1856–1861.	Mixed Min. Man., and Amm.-salts = 172 lb. Nitrogen, 1862 and since.	Mixed Min. Man., and Amm.-salts = 172 lb. N., and silicates, 1862 and since.	Mixed Min. Man., and Nitrate Soda = 86 lb. Nitrogen, 1858 and since.	Mixed Min. Man., and Nitrate Soda = 43 lb. Nitrogen, 1858 and since.	Superphosphate and Amm. salts = 86 l[b.] Nitrogen, 1859 and since.
17.	Plot 7.	Plot 4.	Plot 4–1.	Plot 8.		Plot 9.	Plot 13.	Plot 11.	Plot 11–1.	Plot 11–2.	Plot 14.	Plot 16.	Plot 4–
Nitrogen and Mineral Matter—Percentage in the Dry Substance.													
74	1·74	1·77	1·58	1·82	1·58	1·55	1·58	1·74	2·03	1·95	1·31	1·46	1·9
79	7·70	7·09	7·10	8·07	7·00	7·11	7·37	7·72	6·98	7·12	6·89	7·29	6·1
02	8·02	7·40	7·23	8·45	7·22	7·24	7·46	7·73	7·02	7·13	6·96	7·56	6·1
Composition of the Pure Ash—per cent.													
78	0·43	0·40	0·58	0·35	0·45	0·46	0·46	0·66	0·45	0·51	0·83	0·54	0·7
59	0·70	0·52	0·59	0·46	0·74	0·86	0·91	0·77	0·86	0·82	0·33	0·70	1·3
03	11·92	15·26	16·22	12·78	12·43	8·27	7·64	9·43	5·94	5·92	8·27	8·97	14·7
23	3·49	4·26	4·56	3·22	4·22	3·42	3·34	3·79	3·67	3·68	3·36	3·27	6·4
93	34·60	20·73	18·26	30·66	23·36	35·59	36·68	29·63	36·71	35·79	28·49	32·52	15·8
14	1·53	6·98	7·68	3·12	7·09	3·87	3·70	6·85	5·73	6·23	9·32	5·11	9·5
12	7·92	5·17	8·93	7·01	9·30	7·96	7·86	6·84	7·88	7·80	7·34	8·21	11·5
73	6·76	6·97	7·90	7·36	8·17	5·76	5·67	5·96	5·29	4·98	6·95	6·79	7·5
53	5·55	6·02	5·76	5·83	5·45	14·83	14·94	15·93	17·82	18·45	6·31	6·22	10·6
10	13·00	11·82	9·68	13·06	9·22	5·79	5·73	5·45	4·23	3·74	10·14	11·05	3·7
30	15·35	23·23	21·13	17·46	20·80	16·54	16·44	18·28	15·44	16·24	20·08	18·03	20·2
48	101·25	101·36	101·29	101·31	101·23	103·35	103·37	103·59	104·02	104·16	101·42	101·41	102·4
48	1·25	1·36	1·29	1·31	1·23	3·35	3·37	3·59	4·02	4·16	1·42	1·41	2·4
00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·0

...first 7 years, 1856–62. † Second determination—after treatment with a solution of ammonium-carbonat[e]

—Means of analyses of Mixed-year Samples.

together.			Mixed Mineral Manure, after Ammonium-salts.		
Super-phosphate, and Amm.-salts = 86 lb. Nitrogen, 1859 and since.	Mixed Min. including Potash, and Amm.-salts = 86 lb. N., 1856–1861. *	Mixed Man. excluding Potash, and Amm.-salts = 86 lb. N., 1862 and since. *	Amm.-salts = 86 lb. Nitrogen, 1856–1868. *	Mixed Mineral Manure including Potash, 1869 and since.	
. Plot 4–2.	Plot 10.		Plot 6.		
1·95	1·43	1·84	2·10	1·46	Nitrogen } Per cent. in Dry Matter
6·17	8·19	6·25	6·10	6·32	Crude Ash } Per cent. in Dry Matter
6·18	8·35	6·32	6·29	6·56	Pure Ash } Per cent. in Dry Matter
0·78	0·44	0·60	0·61	0·48	Ferric oxide
1·32	0·63	0·98	1·30	1·33	Manganese oxide
14·70	9·21	9·80	14·38	9·25	Lime
6·43	3·16	5·42	5·66	3·62	Magnesia
15·80	29·51	16·96	18·22	34·29	Potash
9·52	5·77	14·97	8·63	2·64	Soda
11·58	6·83	10·44	5·99	8·75	Phosphoric acid
7·57	6·19	6·76	7·87	7·09	Sulphuric acid
10·66	14·95	12·72	11·72	6·18	Chlorine
3·79	5·25	4·54	6·91	9·82	Carbonic acid †
20·26	21·43	19·68	21·36	17·95	Silica
102·41	103·37	102·87	102·65	101·40	Total
2·41	3·37	2·87	2·65	1·40	Deduct O = Cl.
100·00	100·00	100·00	100·00	100·00	Total

arbonate.

The folding Table VII. (facing this page) shows the composition of the produce of most of the plots for which the amount of crop, of nitrogen, and of total mineral matter, per acre, were given in Part I.—"*The Agricultural Results*" ('Phil. Trans.,' Part I., 1880); and for which the botanical composition was given and considered in Part II.—"*The Botanical Results*" ('Phil. Trans.,' Part IV., 1882).

The manuring of the plots is described at the head of the columns, as in the case of the botanical results given in Part II. In the upper division the percentages in the dry substance—of nitrogen, of crude ash, and of pure ash, are given. The "pure ash" is the amount excluding sand and charcoal and the determination of carbonic acid at low red heat, but substituting for the latter the amount of carbonic acid determined after treatment by ammonium-carbonate. In the lower division of the table the percentage composition of the so-calculated "pure ash" is given.

The results represent for each plot, the average composition of the produce over a considerable series of years; in many cases eighteen years, 1856–1873; but in others for shorter periods, dependent on the changes in the manuring, as indicated in the headings of the columns.

For the earlier years of the eighteen, the nitrogen was generally determined in the produce of each individual year; but subsequently on "*Mixed-year*" samples, made proportionally to the amount of the produce of the plot each year. The average percentage of nitrogen in the dry matter given at the head of each column is obtained by adding the percentages for each individual year when so determined, to the figure obtained by multiplying the determinations on the "*mixed-year*" samples by the number of years they represent, and dividing the total by eighteen, or any less number of years to which the results relate.

The average percentages of ash given are means of determinations made in the produce of each individual year.

The ash-analyses have in most cases been made on "*mixed year*" samples of the ashes for several years, made proportionally to the amount of ash yielded per acre in the crops each year. From the results of the analyses so obtained, the average percentage of each constituent for the eighteen (or fewer) years is calculated, by multiplying the actual determination by the number of years which each analysed mixed ash represents, adding together the results for the separate periods, and dividing by eighteen or any less number of years as the case may be. The results of the individual ash-analyses, 61 in number, upon which the averages given in Table VII. are founded, as above described, are recorded in Appendix Tables I., II., and III.

We will now refer to the results given in the folding Table VII., obtained as above described.

Group 1.—*Plots Without Manure, and with Farmyard Manure.*

In the first vertical division of the folding Table are given particulars of the composition of the mixed herbage of each of the three plots in Group 1;—that continuously

without manure (plot 3); that with farmyard manure for 8 years, and afterwards without manure (plot 2); and that with farmyard manure and a small quantity of ammonium-salts = 43 lb. nitrogen per acre per annum for 8 years, and the ammonium-salts alone each year afterwards. It will be seen that for plot 3 without manure, the average composition is given for the total period of 18 years only; but for plots 2 and 1 respectively, it is given for the 8 years during which the farmyard manure was applied; for the 10 years after the cessation of the application; and for the total period of 18 years. For the better comparison with the composition of the unmanured produce, we will in the first instance refer to that of plots 2 and 1 over the total period of 18 years in each case; referring to the differences of composition over the first 8, and over the next 10 years, afterwards.

For details as to the differences, and the changes, in the botany of the three plots, we must refer to the Appendix Tables in Part II. But reference to the summary Table I. (pp. 144–145), will convey a sufficiently clear idea of the difference in the number of species, and in the proportions respectively, of gramineous, leguminous, and other herbage, in the mixed produce of the plots. It will be seen that that of plot 3, continuously without manure, was by far the most complex, comprising the highest number of species; but it contained a low average percentage of gramineous (68·27), a moderate amount of leguminous (7·48), but a very high percentage of miscellaneous herbage (24·25). The produce of plot 2, with farmyard manure for 8 years (supplying a large amount of both nitrogen and ash-constituents), and afterwards unmanured, contained a considerably higher percentage of gramineous (79·86), but much less of both leguminous and miscellaneous herbage than the unmanured produce. Lastly, the produce of plot 1 with farmyard manure and a small quantity of ammonium-salts each year for 8 years, and afterwards the ammonium-salts alone, contained a still higher average percentage of gramineous herbage (85·87), and still lower percentages of leguminous and miscellaneous herbage.

Referring to the chemical composition, we will first call attention to the percentage of nitrogen in the dry substance of the mixed produce of each of the three plots. In that of plot 3 without manure, with its low percentage of gramineous, moderate amount of leguminous, but very high percentage of miscellaneous herbage, the percentage of nitrogen in the dry matter was 1·66; which is higher than in the separated gramineous, about as high as in the separated miscellaneous, but very much lower than in the separated leguminous herbage of the plot, as shown in Table II. (p. 148). The percentage of nitrogen in the dry substance of the produce of plot 2, with its higher percentage of gramineous, and lower percentages of leguminous and miscellaneous herbage, was much lower, namely 1·38. Lastly, in the dry substance of the produce of plot 1, with its still higher percentage of gramineous, and still lower percentages of leguminous and miscellaneous herbage, the percentage of nitrogen was 1·46; that is higher than in the produce of plot 2 without the ammonium-salts; the herbage with the ammonium-salts being more leafy, and also

less mature, as indicated by abnormally dark green colour, the result of excessive nitrogenous in relation to the available mineral supply.

Next as to the amount of *ash* in the dry substance of the produce of the three plots. Taking for illustration the percentage of "*pure ash*"—that is excluding sand and charcoal, and the first carbonic acid determination, but including the higher or corrected carbonic acid—it is seen that it is higher in the produce of the two plots which had received farmyard manure in the earlier years, than in that of the continuously unmanured herbage—7·52, and 7·17, against only 7·03 in the latter.

Turning now to the percentage composition of the pure ash, it may in the first place be observed, that the ash of the unmanured produce (plot 3), with its small proportion of gramineous, only moderate amount of leguminous, but very large amount of miscellaneous herbage, contained the lowest percentage of silica, but on the other hand the highest percentage of both lime and carbonic acid. Further, more detailed comparison of the results indicates clearly what was the character of the mineral exhaustion of the continuously unmanured plot. Thus, there was, without manure, not only a less percentage of ash in the dry matter of the produce, but the ash itself contained much less potash, but about one-and-a-half time as much lime and rather more magnesia and soda, than that of the produce of plots 2 and 1, where farmyard manure had been applied. Then as to the acids, the ash of the unmanured produce contained considerably less phosphoric acid, but more sulphuric acid and less chlorine.

Obviously the mineral exhaustion of the unmanured plot was characteristically that of potash and phosphoric acid; the former chiefly replaced by lime, but partly by soda; and the latter by sulphuric acid supplied by the stores of the soil itself. The greatly increased amount of chlorine in the ash of plot 1, receiving ammonium-salts, is obviously due to the chlorine of the ammonium-chloride used; and its high percentage is also consistent with the relatively immature condition of the gramineous herbage of the plot, as already referred to.

In confirmation, and further illustration, as to the characteristic mineral exhaustion under the unmanured condition, it will be of interest to compare the composition of the ash of the produce of plots 2 and 1 over the 8 years of the application of farmyard manure, with that over the next 10 years during which the application was discontinued. It is seen that in each case there was a considerable reduction in the percentage of potash in the ash after the cessation of the application of farmyard manure; whilst, on the other hand, the percentages of lime, magnesia, and soda, were in each case higher over the 10 later years; and in the case of plot 2 the amount of carbonic acid also increased over the later years. In fact, after the cessation of the application of the farmyard manure, the tendency of the change in the mineral composition of the produce was towards that of the continuously unmanured produce.

In saying that potash has been replaced by lime and soda, and phosphoric acid by

sulphuric acid, it is of course not implied that lime and soda fulfil the same physiological function in the plant as potash, or sulphuric acid the same as phosphoric acid. The supposition is that, according to the available supply, so will particular plants be developed, and so will the character of their development be determined—the proportions of leaf, stem, tendency to maturation, etc. In other words, with difference of mineral composition, there will be difference in organic composition. To this point reference will be made in more detail further on.

The average percentages of silica in the ash of the produce of the 18 years is not very widely different in the three cases—23·06, 26·87, and 23·82. But, as will be shown later, there was more than twice as much silica taken up per acre on each of the plots 2 and 1 which had received farmyard manure more recently, than on the continuously unmanured plot 3. Again, the percentage of carbonic acid in the ashes is the less, the greater the proportion of the gramineous, and the less that of the leguminous and the miscellaneous herbage in the produce, namely—12·15 without manure (plot 3), 9·20 with a residue of farmyard manure (plot 2), and only 5·55 with the residue of farmyard manure and ammonium-salts in addition (plot 1); the percentages of non-gramineous herbage in the three cases being—31·73, 20·14, and 14·13.

There is, then, in these first illustrations, consistent evidence of the connection between the ultimate chemical composition of the mixed herbage, and the supplies at command within the soil. Further, these supplies to a great extent determine, both the description of plants encouraged, and the character of their development. Lastly, the influence of these induced factors is clearly traceable in the chemical composition of the mixed produce.

Group 2.—Plots with nitrogenous manures alone.

This group includes three plots, to each of which nitrogenous manure alone was applied; to plot 5 as ammonium-salts alone; to plot 15 the same amount of nitrogen, but as nitrate of soda; and to plot 17 with half the quantity of nitrogen as nitrate of soda. These conditions obviously involve even still greater exhaustion of the mineral supplies of the soil than the growth without manure; as, under the influence of the nitrogenous supply, luxuriance will be forced to the utmost limits that the available supply of mineral constituents will permit. It is to be borne in mind, however, that as the ammonium-salts are applied as an equal mixture of sulphate and chloride, sulphuric acid and chlorine are thus provided; whilst in the nitrate of soda, soda is liberally supplied.

Reference to Table I. (pp. 144–145) will show that under these conditions of relatively excessive supply of nitrogen, the number of species, especially on plot 5 with ammonium-salts alone, was considerably reduced compared with that on the unmanured plot. It is also seen that the produce of all three plots (again of plot 5 especially) contained much higher percentages of gramineous, much lower of

leguminous, and lower but at the same time comparatively high percentages of miscellaneous herbage.

Turning now to the results in Table VII., it is seen that notwithstanding that the herbage was so prominently gramineous, the percentage of nitrogen in the dry substance was in the case of plot 5 with the ammonium-salts much higher, and in those of plots 15 and 17 with nitrate of soda higher, than in normally matured separated gramineous produce—namely, 2·16, 1·89 and 1·74. With the ammonium-salts there was at the same time a much lower percentage of total mineral matter (pure ash) than without manure—6·02 against 7·03; though with nitrate there was not much less than without manure—6·84 and 7·02, owing to the amount of soda supplied and taken up. These results, showing high percentages of nitrogen, and low percentages of mineral matter, are quite consistent with the evidence of forced luxuriance and immaturity, afforded by the abnormally leafy growth, and dark green colour of the herbage, characters which were much more marked with the ammonium-salts, than with the nitrate.

The figures relating to the composition of the ash show that that of the produce by ammonium-salts contained less potash, less lime and carbonic acid, but more magnesia and soda, and also more phosphoric acid, sulphuric acid, and chlorine, than that of the unmanured produce. The ashes of the nitrate of soda plots show again, less potash, lime, and magnesia; also less phosphoric acid, sulphuric acid, and chlorine, than that of plot 5 with ammonium-salts; but on the other hand, very much more soda, and very much more carbonic acid. There is in the ash of the produce by ammonium-salts, with a deficiency of potash, a higher percentage of soda, though none was supplied, than in that without manure. But, not only the percentage of soda in the ash, but the amount of it taken up per acre on plots 15 and 17 with nitrate of soda, was much greater than on plot 5 with ammonium-salts, and in a greater degree in excess of that in the unmanured produce. It is to be observed too, that with the nitrate of soda there was also more potash taken up per acre than without manure; probably partly due to the ready permeation of the nitrate, tending to extend root-distribution and collection to lower layers, and partly to the action of the soda in liberating potash within the soil and subsoil.

Not only, however, does the soda of the nitrate applied greatly increase the amount of it in the ash of the produce, but in the case of the ammonium-salts the ash of the produce contains much more of both sulphuric acid and chlorine than that of the produce grown either without manure or with nitrate of soda. The ash of the nitrate of soda produce on the other hand, shows percentages of magnesia, phosphoric acid, sulphuric acid, and chlorine, very similar to those without manure. With, however, the larger proportions of non-gramineous and especially of miscellaneous herbage in the produce of the nitrate of soda plots, than in that by ammonium-salts, the ashes contain considerably more carbonic acid. Lastly, the percentage of silica does not vary greatly in either case from that in the ash of the unmanured produce;

but the amounts of silica taken up per acre were much higher under the influence of the nitrate of soda than under that of the ammonium-salts; and it will be seen as we proceed that high silica is frequently associated with high soda.

Here again, then, as in the case of group 1, and as will be found generally as we proceed, the conditions of supply within the soil, greatly influence the description of plants encouraged, and the character of their growth, and they are, moreover, clearly reflected in the composition of the product.

Group 3.—*Plots with Mineral Manures alone.*

The results of this group will bring to view some striking contrasts, both to those of group 2, and among the individual results which it comprises. These relate to the produce of plots receiving mineral manures alone, that is excluding nitrogen. The first plot, 7, received every year a complex and pretty complete mineral manure, consisting of superphosphate of lime, and salts of potash, soda, and magnesia. Plot 4 was for the first three years substantially unmanured (receiving only sawdust). It was then sub-divided into 4–1 and 4–2; and from that time 4–1 received superphosphate of lime alone each year. The third plot (8), was manured for the first six years with the same mixed mineral manure, including potash, as plot 7, and afterwards it received otherwise the same manure, but excluding the potash.*

Reference to Table I. (pp. 144–145) will show that a prominent characteristic of the produce of these plots was an unusually low percentage of gramineous herbage; with potash very high percentages of leguminous herbage, but without it comparatively small amounts. Lastly, with potash, there was with the high amounts of leguminous, comparatively little miscellaneous herbage; but without potash, and with comparatively low proportions of leguminous, very high percentages of miscellaneous herbage. The produce per acre of both gramineous and leguminous herbage was very much higher with than without potash, as also was the total amount of produce. Further, excepting the unmanured produce, that of this group without nitrogenous manure, and therefore restricted luxuriance and limited competition, comprised a greater total number of species, especially miscellaneous species, than that of any of the other groups. Lastly, with the relative excess of mineral to nitrogenous supply, the herbage was characteristically stemmy and matured.

Under these conditions as to supply of constituents, as to description of herbage, and as to its character of development, the percentage of nitrogen in the dry substance of the produce is generally lower than in the case of the 2nd group with excessive nitrogenous supply, and defective maturing tendencies. It, however, obviously varies according to the variations in the proportion of the different descriptions of herbage—being higher in the produce of plot 7, and in that of the earlier years of plot 8, with liberal potash supply, and large amounts of the highly nitrogenous leguminous herbage, than in that of plot 4–1 with superphosphate alone,

* Plot 8 also received sawdust (but practically without effect) first 7 years, 1856–62).

or in that of the later years of plot 8, without potash. Again, with the relative excess of mineral supply, the percentage of total mineral matter (pure ash) in the dry substance of the produce is, in each case higher than in that without manure, and in a greater degree higher than in that with nitrogenous manure alone. Further, it is especially high where potash was liberally supplied, and largely taken up.

Referring to the composition of the ash, as no nitrogen was applied to either of these plots, the results will, in the first instance, be most appropriately compared with those relating to the unmanured produce (plot 3). The chief point to remark is, that on plot 7, with a liberal supply of potash, soda, lime, magnesia, phosphoric acid, and sulphuric acid, there is in the ash 34·60 per cent. of potash against only 19·10 without manure; of phosphoric acid 7·92 against 5·24; and of sulphuric acid 6·76 against 5·98.

But, of lime, of magnesia, and of soda, although each was liberally supplied, there was in the ash less than in that of the unmanured produce—of lime, only 11·92, against 17·26, of magnesia 3·49 against 4·58, and of soda only 1·53 against 6·88 without manure. Thus, when the mineral constituents more directly involved in the development and maturation of the organic substance are liberally supplied, they are found in much increased proportion in the produce; whilst, under such conditions, those of less specially functional importance are, even though liberally provided, found in less proportion in the ash than without manure. For example, it may be stated that there was less than half as much soda per acre in the much higher produce of plot 7 where it was liberally supplied, but in conjunction with potash, than where it was not supplied at all, as without manure. Here, again, it is to be observed in regard to this striking result, that the potash and the soda are not to be considered as mutually replaceable in the fulfilment of the same physiological functions. In the presence of a full supply of potash, the vegetation takes a normal and progressive development accordingly; but if there be a deficiency of it, the available soluble matters are, to a greater or less extent taken up and remain; but the carbon-assimilation is abnormally restricted, and the herbage continues in a merely vegetative, backward, and immature condition. That is to say, it is under conditions of exhaustion of the constituents essential for full development, that an excess of others is found in the produce, which itself then remains in a condition of development limited by the deficiency of supply of the more essential matters. It has been seen, however, that other bases than potash, though not fulfilling its special functions may, independently of any other special office, be also, and perhaps chiefly, of importance as *carriers of nitric acid.*

Some of the above points are further illustrated by a comparison of the mineral composition of the produce of plot 7 with the full supply of potash, with that of plot 4–1 with (for the last 15 years) the same amount of superphosphate, but with neither potash, soda, nor magnesia, supplied. With the potash, there was much more total produce, both gramineous and leguminous, especially the latter. The

gramineous herbage was characteristically stemmy and matured, and the leguminous was well developed and comparatively ripe.

Then as to the composition of the ash :—With the supply of potash the percentage of it is 34·60, but without the supply (plot 4–1) it is only 18·26, or little more than half as much. Again, without the supply of either potash, soda, or magnesia (plot 4–1), the percentage of soda is 7·68 against only 1·53 where soda, but in conjunction with potash, was supplied. The percentage of lime is 16·22 instead of only 11·92 with the potash supply; and that of magnesia is 4·56 instead of only 3·49 where it was supplied. That is, in the defect of potash the percentage of it is greatly diminished, and that of soda, lime, and magnesia, is increased; but coincidently, the amount and character of the produce are materially lowered. Further, in the produce without potash (plot 4–1), but with the same supply of superphosphate, which thus becomes relatively predominant, the percentage of both phosphoric acid and sulphuric acid is increased. But, with the higher proportion of total gramineous, much lower proportion of leguminous—indeed much lower of total non-gramineous herbage—the percentage of silica is higher, 21·13 against 15·35; and that of carbonic acid is lower, 9·68 against 13·00.

Within this mineral manured group, it remains to consider the difference in the composition of the produce of plot 8, during the six years of the application of potash, and during the period subsequent to the cessation of the application of it. In the first place it should be borne in mind, that after the cessation of the application, the amount of total produce much diminished; the diminution being very marked in both the gramineous and leguminous herbage, whilst that of the miscellaneous herbage was increased. Further, the herbage generally, and very prominently the gramineous herbage, was more leafy, and remained in a backward condition of development and of maturation. Referring to the composition of the ash, the Table (VII.), shows that before the cessation, the percentage of potash in the ash was 30·66, but afterwards only 23·36; before, the percentage of soda was 3·12, but after 7·09; the percentage of lime was, however, not materially affected. As before, with the same supply of superphosphate, now that it becomes more dominant, the percentage in the ash of both phosphoric acid and sulphuric acid is higher. The percentage of silica is also higher after the cessation of the application of potash, and the consequent more leafy character of the herbage; and, with this, that of carbonic acid is coincidently lower, notwithstanding a higher proportion of total non-gramineous herbage.

As the variation in the amounts of potash available to the growing vegetation constitutes the most characteristic difference between the condition of the several plots of this group, it might be expected that the variations in the percentage of it in the ashes would be very great. Accordingly, with a long continued annual supply of potash (plot 7), there were 34·60 per cent. of it in the ash of the produce; with a shorter continuance of the supply (plot 8) 30·66, after the cessation of the supply

on the same plot 23·36; and where it had not been supplied at all (plot 4–1) only 18·26.

Here then, in the case of this mineral manured group, as in that with purely nitrogenous manures, the mineral composition of the produce was very directly affected by the mineral supplies; whilst the variations in composition in this respect are coincident with marked variations in the description of plants favoured, and in the character of their development.

Group 4.—*Plots with Mineral and Nitrogenous Manures together.*

The fourth vertical division of Table VII., records the results relating to this group. It includes a large number of plots, each of which received both mineral and nitrogenous manure. The plots 9, 13, 11, 11–1, 11–2, 14 and 16, each received annually the same complex mineral manure, consisting of superphosphate of lime, and salts of potash, soda, and magnesia, as plot 7 of the 3rd group. But whilst to plot 7 no nitrogenous manure was applied, to each of these plots nitrogenous as well as mineral manure was applied; to plots 9 and 13 as ammonium-salts, in the same amount as was used alone on plot 5, and to the plots 11, 11-1 and 11–2, also as ammonium-salts, but in nearly double the amount applied to 9 and 13. Plot 14 received, with the mineral manure, the same amount of nitrate of soda as was applied alone on plot 15, and containing the same amount of nitrogen as the ammonium-salts of plots 5, 9, and 13. Plot 16 received, besides the mineral manure, half the amount of nitrate of soda as was applied to plots 15 and 14. Plot 4–2 received the same amount of ammonium-salts as plots 9 and 13, but with superphosphate alone, instead of the full mineral manure. Lastly, plot 10 received the same amount of ammonium-salts each year as plots 9 and 13, and during the first six years, 1856–'61, the same complex mineral manure, including potash, as plot 7, and most of the plots of this group; and during the subsequent years otherwise the same mixed mineral manure, but excluding potash.

Thus, among the members of this group, there was great variety in the manurial conditions; some in the character of the mineral supplies, but more so far as the description and amount of the nitrogenous manures are concerned. We shall, therefore, have many points of comparison or contrast within the group; and also marked points of contrast between members of this and the other groups—on the one hand with those having nitrogenous manures alone, and on the other with those with mineral manures alone.

It has been fully illustrated—that nitrogenous manures alone gave a prominently gramineous produce, but that with the relative excess of nitrogen and deficiency of mineral supply, the gramineous herbage was abnormally leafy and immature; on the other hand—that the mineral manures alone did not increase the luxuriance of the grasses, but tended much to their stemming and maturation, and at the same time greatly enhanced the growth of plants of other families, especially of some leguminous species.

When, however, as under the conditions we have now to consider, the nitrogenous and mineral manures are used together, the botanical character of the herbage is totally different from that induced by either of the two descriptions of manure used separately. The figures given in Table I. (pp. 144–145) bring this very prominently to view. It is seen that the members of this group (4) show much higher percentages of gramineous herbage than those of either the 2nd or the 3rd group; much less leguminous herbage than those of the 3rd, and much less miscellaneous than those of either the 2nd or the 3rd group. Thus, under the influence of the nitrogenous and mineral manures together, the gramineous herbage is brought into very great prominence; but, instead of being leafy and immature as when the nitrogenous manures are used alone, it is now with mineral supply in addition—and especially of potash—extremely stemmy, with great tendency to maturation. The result is a total produce about one-and-a-half time as great as with either description of manure used alone. Further, although in the majority of the cases the mineral manure contained the same amount of potash as, when it was used without nitrogen induced such a great development of leguminous herbage, now, when used in conjunction with nitrogenous manures which so prominently favour luxuriance of the grasses, there is scarcely any leguminous herbage—with ammonium-salts only a trace, and with nitrate, though more, still very little. There is, at the same time, especially with ammonium-salts, a greatly reduced total percentage of miscellaneous herbage; though a few individual species develop luxuriantly, especially where the nitrogenous supply is in the form of nitrate of soda.

We have then, among the members of this group (4), to consider the composition of very characteristically gramineous, and for the most part very stemmy, herbage; and we have especially to consider the variations in chemical composition dependent on any differences in the mineral supply, and on any differences in either the description or the amount of the nitrogenous manure—conditions which affect the botanical composition, and the character of development of the herbage; whilst these, again, materially affect the chemical composition. We have, besides, to compare and contrast the chemical composition of such herbage, with that of the very different produce developed by either of the two characteristically different descriptions of manure when used separately.

As usual, the first point of significance to notice is—the percentage of nitrogen in the dry substance of the mixed herbage in the different cases.

It was seen in Table II. (p. 148), that the separated gramineous herbage of produce grown without nitrogenous manure contained about 1·36 per cent. of nitrogen in its dry substance. But here we have, in the case of mixed herbage which is very prominently gramineous, a range from only 1·31 per cent. in that of plot 14, with the full mineral manure and nitrate of soda, to 2·03 per cent. on plot 11–1, with the same mineral manure, but with much more nitrogen, and supplied in the form of ammonium-salts. This wide range in percentage of nitrogen, represents a wide range in the

character of the herbage, both as to the proportion of the stem produced and as to the condition of ripeness. Thus, on plot 14, with the lowest percentage of nitrogen in the dry substance, the mixed herbage contained on the average about 92 per cent. by weight of Gramineæ, whilst the grasses were always extremely stemmy, and ripened so early that the produce generally required cutting some days, and sometimes more than a week, before that of any other plot. On plot 11–1, on the other hand, with the excessive amount of nitrogen as ammonium-salts, the produce shows an average of 2·03 per cent. of nitrogen in its dry substance, or about one-and-a-half time as much as in the separated unmanured gramineous herbage. Yet here the herbage is even more exclusively gramineous than that of plot 14. But, owing to the nitrogen applied being in excessive amount, both actually, and in relation to the mineral supplies concurrently available, vegetative luxuriance was continued, and maturation was retarded; the result being, although a stemmy and often laid, nevertheless a succulent, dark green, and comparatively immature produce.

These two extremes strikingly illustrate the connection between variation in the percentage of nitrogen in the produce, the character and amount of the supply by manure, and the character of the resulting herbage accordingly. But the point will be further illustrated as we proceed.

The percentage of total mineral matter (pure ash), in the dry substance of the produce, is seen to vary within this group, from 6·18 in that of plot 4–2 with ammonium-salts and superphosphate of lime annually applied, to 7·24 in that of plot 9, and 7·46 in that of plot 13, each with the same amount of ammonium-salts and of superphosphate, but with salts of potash, soda, and magnesia, in addition. The low percentage of mineral matter in the dry substance of the produce of plot 4–2, is in fact associated with very limited growth in defect of potash supply, and the higher percentages in the other cases with very stemmy development of the grasses under the influence of the full mineral supply including potash.

Let us turn now to the composition of the ashes of the produce: it is seen that in that of plot 9, with ammonium-salts and the complex mineral manure containing potash as well as phosphoric acid, there is 35·59 per cent. of potash, against only 19·10 in that of the unmanured produce (3), and only 15·80 in that of the produce of plot 4–2, with the same amount of ammonium-salts and superphosphate, but without potash. That is to say, with the supply of potash in the manure, its percentage in the ash of the produce was more than doubled. In fact, as shown in Table VIII. (pp. 198–199), the quantity of potash in the produce per acre was nearly quadrupled; being only 31·5 lb. in that of plot 4–2, and 124 lb. in that of plot 9.

On the other hand, with the liberal supply of potash on plot 9, and the high percentage of it in the ash, there was little more than half as much lime (8·27 against 14·70 per cent.), little more than half as much magnesia (3·42 against 6·43), and not half as much soda (3·87 against 9·52), as in the ash of the produce of plot 4–2, without supply of either potash, soda, or magnesia. That is, in defect of potash supply,

there was, in proportion to the potash, more lime, more magnesia, and more soda, taken up from the stores of the soil itself, than on plot 9, where lime was equally supplied, and both magnesia and soda were liberally provided by manure. In fact, the quantity of lime in the produce per acre of plot 4–2 was about the same as in that of plot 9, and that of soda was much greater than on plot 9. As before said, such apparent substitution of lime, magnesia, and soda, for potash, does not indicate that the one or the other acts vicariously for potash in its special function; for this difference in the mineral matters taken up and retained, is associated with marked difference in the description of plants encouraged, and in the character of their development—in other words, with the character and amount of the organic matters formed. This point will be illustrated in some detail further on. Obviously, however, the other bases may have been of service, to a greater or less extent, *as carriers of nitric acid.*

Then as to the phosphoric acid, which is equally supplied on both plots—on 9 with, and on 4–2 without, potash, soda, and magnesia. On plot 4–2, therefore, although the supply of phosphoric acid is actually the same, it is in proportion to other constituents much more predominant. The result is that, although the actual quantity of phosphoric acid in the crops *per acre*, was one-third more on plot 9 than on plot 4–2, yet its percentage in the ash of the produce was nearly one-and-a-half time as much in that of plot 4–2, as in that of plot 9—11·58 against only 7·96. This larger proportion of phosphoric acid to other constituents in the ash of the produce of plot 4–2, is quite consistent with the difference in the description of the herbage, and in the character of its development, in the two cases. Thus, on plot 9 there was a luxuriant, but very stemmy, and fairly matured, chiefly gramineous produce; that is a produce characterised by much carbon-assimilation in relation to the nitrogen; and with this there was a very high percentage of potash in the ash (35·59), but only a moderately high percentage of nitrogen in the dry substance, namely 1·55, and coincidently a relatively low percentage of phosphoric acid in the ash. On plot 4–2, on the other hand, with none of these characters of growth, and little more than two-thirds as much produce per acre, there was a very low percentage of potash in the ash (15·80), a very high percentage of nitrogen in the dry substance (1·95), and with this a relatively very high percentage of phosphoric acid in the ash.

It will be clearly shown in a subsequent Section, that an abnormally high percentage of nitrogen in the herbage is by no means to be taken as indicating high food-value. In fact, when high percentage of nitrogen is found in chiefly gramineous herbage, it is evidence of deficient carbon-assimilation relatively to the nitrogen. In other words, high percentage of nitrogen is, under such circumstances, an indication of a deficient proportion of carbohydrates formed, and also of immaturity.

Lastly as to the comparative composition of the ash of the produce of plot 9 with, and of plot 4–2 without, the supply of potash, soda, and magnesia; it is seen that, under the defective conditions on plot 4–2, with defective growth accordingly, there

is, with the high percentage of nitrogen in the produce, and with the high percentage of phosphoric acid in the ash, also a relatively high percentage of sulphuric acid—7·57 against only 5·76; but there is, on the other hand, relatively low percentage of chlorine; and, as has been seen in other comparable cases, there is, coincidently with the higher percentage of silica in the ash (20·26 against 16·54), a lower percentage of carbonic acid (3·79 against 5·79).

We may next more briefly compare the composition of the produce of plots 13, 11, 11–1, and 11–2, with that of plot 9, which has been so fully considered. All these plots received the same complex mineral manure including potash, and all received nitrogen as ammonium-salts. First comparing plots 9 and 13, both of which received, besides the mineral manure, the same amount of ammonium-salts; but plot 13 received cut wheat straw every year in addition. The primary object of this application was to try the influence of a supply of silica in somewhat the same condition as in farmyard manure. The straw-chaff at first showed practically no result; but, after a time, it seemed to have a protecting or mulching effect on the early shoots; and it was evident that, as it slowly decomposed, it yielded a little of both nitrogen and some mineral matters to the growing crop. In fact, on the average of years, the crop per acre contained notably more of both nitrogen and potash, and slightly more of lime, magnesia, soda, phosphoric acid, sulphuric acid, and silica. The result was, that there was induced on plot 13, a somewhat more luxuriant, and a more prominently gramineous herbage (90·72 instead of 85·95 per cent.); and these conditions were accompanied by a slightly higher percentage of nitrogen in the dry substance—1·58 against 1·55; a slightly higher percentage of total ash (pure)—7·46 against 7·24; and in the ash by a higher percentage of potash—36·68 against 35·59; but slightly lower percentages of lime, magnesia, and soda, also of phosphoric acid, sulphuric acid, carbonic acid, and silica.

Thus, neither the conditions of the manuring, nor the characters of the growth, were widely different; and accordingly the differences in the ultimate chemical composition of the produce are comparatively small; though, such as they are, they are consistent with those in the botanical composition, and in the characters of development.

Next as to plots 11, 11–1, and 11–2. Originally these plots constituted only one plot—11. Compared with plot 9, the difference in the treatment was, that plot 11 received for the first 3 years twice as much ammonium-salts as 9, but for the next 3, only an equal amount; the supply corresponding over the six years to an average of 129 lb. of nitrogen per acre per annum, instead of only 86 lb. on plot 9. Over the next 12 years, 1862–1873 inclusive, the plot was divided into 11–1 and 11–2. Both halves received every year twice as much ammonium-salts as plot 9, but 11–2 received in addition artificial silicates; for 9 years a mixture of silicate of soda and of silicate of lime, and afterwards of silicate of soda only.

As compared with plot 9, therefore, the plots 11 received a great excess of

ammonium-salts, both actually, and relatively to the mineral manures applied; though in the case of 11–2, where silicates were also used, the excess of nitrogen was less in relation to the mineral supply than on plot 11–1. Referring to Table VII. (facing p. 175), as the results given for plot 11, in the first of the three columns relating to these plots, apply to a period of only 6 years, and we have not results for the same separate period for plot 9, and other plots, we need not discuss them in much detail; but will refer specially to those of 11–1 and 11–2, each of which relates to a period of 12 years; though even these do not compare strictly with those of plot 9, which relate to the total period of 18 years.

In the first place, whilst the average percentage of nitrogen in the dry substance of the produce of plot 9 was only 1·55, that in the produce of plot 11–1, with the greatest excess of nitrogen relatively to mineral supply, was 2·03, and that in the produce of plot 11–2, with a somewhat less relative excess of supply, was 1·95. This was the case notwithstanding that the produce of the plots 11–1 and 11–2 with the excessive supply of nitrogen was, over the years of separation referred to, still more exclusively gramineous than that of plot 9—94·11 and 96·39 against 85·95. There is here clear evidence, therefore, of excess of nitrogen, or rather of deficient carbon-assimilation in relation to the nitrogen; and there was also corresponding immaturity of the produce. There was, in fact, not only an excess of nitrogen in relation to the mineral matters taken up, but an excess in relation to the capabilities of growth of the plants within the season, under the limitations of the climatal conditions of light, heat, and moisture; and hence the percentage of nitrogen in the dry substance of the herbage remained very abnormally high for almost exclusively gramineous produce.

The figures in the Table further show; that there was a remarkable similarity in the percentage composition of the ashes of the produce of the two plots, 11–1 and 11–2. The percentages of lime, of magnesia, and of phosphoric acid, are nearly identical in the two cases; and those of sulphuric acid, of chlorine, and of carbonic acid, differ but little. The most characteristic differences are, that with the silicate of soda applied to 11–2, the percentage of soda is rather higher—6·23 against 5·73, and with this, that of potash is rather lower—35·79 against 36·71.

Lastly, there is, with the supply of soluble silicate, a rather higher percentage of silica in the ash—16·24 against 15·44.

It may here be observed, that it is generally found that, in comparable cases, an increase in the amount of silica is associated with an increase in that of soda. It may further be observed, that the increased percentage of silica in the ash where silicates were supplied, represents an increase of only about 6 lb. of silica per acre per annum in the produce, though a large amount of soluble silica was annually applied in the manure. The application of silicates to grain crops has been equally without any marked effect in increasing the amount of silica in the straw; whilst high percentage of silica in straw is generally associated with low condition as to stiffness and

strength; these qualities depending on a good development of the woody substance, which obviously would reduce the proportion of silica. So far as the action of artificial silicates applied as manure is concerned, it would seem that the bases have more effect on the soil, especially in the case of the mixed herbage, than the silica itself on the plants.

There is more, but not much more, difference between the composition of the ashes of the plots 11–1 and 11–2, and that of the ash of plot 9. The most marked points are that, with the greater amount of soda in the ashes of the produce of plots 11–1 and 11–2, there is less lime; and with the greater amounts of chlorine, due to the larger quantities of ammonium-chloride applied, there is rather less of carbonic acid, and of silica, and even of sulphuric acid, notwithstanding that part of the extra ammonium-salts applied is as sulphate. Lastly in regard to the comparison between the composition of the produce of plot 9 with that of the plots 11–1 and 11–2, it may be observed that the small differences are consistent with the differences in the character of the produce. Thus, that of the plots 11–1 and 11–2 were more luxuriant, but less matured, and it contained accordingly a higher percentage of nitrogen; and with a relatively deficient mineral supply available, there was a lower percentage of ash (pure); and with the lower condition of maturation, there was a larger proportion of the less essential, that is of the less functionally important constituents—soda and chlorine.

The next comparison—that between the composition of the produce of plots 9 and 14, will bring to view much more striking differences.

It is to be borne in mind, that both plots received annually the same complex mineral manure including potash, and also both the same quantity of nitrogen—but applied as ammonium-salts to plot 9, and as nitrate of soda to plot 14. With the nitrate the herbage was still more prominently gramineous than with the ammonium-salts—92·2 against 85·95 per cent. Again, whilst on plot 9 with the ammonium-salts, 13 grasses contributed more than 1 per cent. to the produce, on plot 14, with the more rapidly acting nitrate, only 8 gramineous species did so; and of these two free-growing grasses—the *Poa trivialis* and the *Bromus mollis*—together contributed nearly half of the total produce.

Further, it has already been explained, that this comparatively simple, and very luxuriant gramineous herbage, was very stemmy, and was ready for cutting a week or more earlier than that of plot 9; and that it was, under these conditions of great stemminess and early maturation of very prominently gramineous herbage, that the percentage of nitrogen in the dry substance of the produce was the lowest in the group—1·31 against 1·55 in that of plot 9, and nearly or over 2 per cent. in that of some other plots. It was also under the same conditions that, although there was more total mineral matter in the crop per acre on plot 14, the percentage of it in the dry substance was lower than in the produce of plot 9—6·96 against 7·24. In other words, owing to the greater amount of carbon assimilated in relation to a given

amount of nitrogen and of mineral matter taken up, the percentage of both was lower in the final product.*

Then as to the comparative mineral composition of the produce of the two plots (14 and 9), as indicated by the percentage composition of their ashes: Neither the percentage in the ash, nor the actual quantity in the crop per acre, of either lime or magnesia differed at all materially in the two cases—lime 8·27 and 8·27, magnesia 3·36 and 3·42 per cent. But the differences in the amounts of potash and of soda are very marked and characteristic. Thus, with the same amount of potash supplied in the two cases, the percentage of potash in the ash of the produce of plot 9, where ammonium-salts were used, was 35·59, against only 28·49 in that of the produce of plot 14 where nitrate of soda was employed.

On the other hand, with the application of nitrate of soda, the ash contained 9·32 per cent. of soda, against only 3·87 per cent. where the ammonium-salts were used.

It seems at first sight anomalous, that the ash of such prominently stemmy and ripe gramineous produce should contain a comparatively small amount of potash, and large amount of soda. But when it is borne in mind that the great luxuriance was directly due to nitrogen supplied in nitrate of soda, it is not surprising that so much soda had entered the plant, and had been retained within it. Further, consistently we find that, whereas the ash of the produce of plot 9, where about half the nitrogen applied was as ammonium-chloride, contains 14·83 per cent. of chlorine, that of plot 14 where the nitrogen was applied as nitrate, contains only 6·31 per cent. of chlorine. With this much smaller amount of chlorine in the ash of the produce of the nitrate plot, there is more sulphuric acid—6·95 against 5·76 per cent.; considerably more carbonic acid—10·14 against only 5·79; and, notwithstanding this, there is an increase in the percentage of silica also—20·08 against 16·54. But here, again, an increased amount of silica is associated with an increased amount of soda.

Evidence has been adduced pointing to the conclusion, that lime and soda, and probably other bases—whatever other function they may perform—are at any rate to a great extent of importance as *carriers of nitrogen as nitric acid* into the plant. But it must not therefore be assumed, that the fact of the chlorine of ammonium-chloride applied as manure appearing largely in the ash, is evidence that nitrogen has to a considerable extent been taken up as an ammonium-salt. Thus, in the case of the continuous wheat experiments, it is found that should there be rain and drainage even within a few days after the application of ammonium-salts to the land, the drainage-water will, after a few hours running, contain only a trace of ammonia, whilst the nitric acid will be increased in amount in very obvious relation to the quantity of ammonia applied. It may be added, that the sulphuric acid and

* It may be added, that subsequently to the period to which the results we are now considering relate, a few free-growing weeds, especially *Anthriscus sylvestris* and *Rumex acetosa*, attained considerable prominence, reducing therefore the percentage of the gramineous herbage.

chlorine in artificial manures are, at any rate in the case of the Rothamsted soil and subsoil, to a great extent carried off in the drainage in combination with lime and soda.

It has been seen, that the difference in the supplies by manure—the provision of the nitrogen in the one case as ammonia, and in the other as nitric acid, and in association in the one case with sulphuric acid and chlorine, and in the other with soda, influenced in a marked degree the botanical composition of the herbage, that is the description of plants encouraged, and also the character of their development. Again, the characteristic difference in the supplies available to the growing plants within the soil were, in a very marked degree, reflected in the chemical composition of the produce. In fact, as already more than once pointed out, the composition of the mixed herbage of grass-land, with the great variety of root-range, and root-habit developed, shows even more than does that of an individual plant growing separately, a very close relation with the available supplies within the soil.

In the case of a fully ripened crop, the final product—the seed, may have within very narrow limits a definite composition; yet the *total plant*, even of such a crop, will show a very wide range of composition under varying conditions of supply; but, in a greater degree still, will the composition of the mixed herbage show variation with variation in the supplies available. The point of practical significance obviously is, that the supplies within the soil very directly influence the matters taken up, and that these again so directly determine the description of plants encouraged, and the character of their development; whilst it is upon these that the value of the mixed produce depends. Hence, it is obvious that caution and careful observation are needed when active artificial manures are used for grass-land, the value of the produce of which depends so much upon quality as well as quantity.

The next results to consider are those obtained on plot 16, which received annually the same complex mineral manure including potash, as plots 9 and 14; but with only half as much nitrate of soda as was applied to plot 14, supplying, therefore, only half as much nitrogen as was applied to either 9 or 14.

Compared with the produce of plot 14, with twice the quantity of nitrate and much more forced luxuriance, that of plot 16 was much less prominently gramineous, containing on the average of the 3 separations only 81·34, instead of 92·21 per cent.; but it contained much more of both leguminous (3·83 against 0·63), and miscellaneous herbage (14·83 against 7·16 per cent.). The gramineous herbage was, moreover, much more complex, 11 instead of only 8 species each contributing more than 1 per cent. to the produce; and of these not one as much as 15 per cent., whilst on plot 14 with the greater amount of nitrate and more forced luxuriance, two contributed each more than 20 per cent. to the produce. Again, the herbage with the smaller application of nitrate, and therefore with less nitrogen in proportion to the mineral supplies, and less forced luxuriance of the grasses, was much less stemmy, and was by no means so rapidly matured.

Under these much more favourable conditions so far as the character and quality

of the herbage was concerned, the percentage of nitrogen in the dry substance of the produce was rather higher—1·46 against 1·31, due to the less stemmy and less ripe condition of the grasses, and to the greater proportion of the more highly nitrogenous, leguminous, and other non-gramineous herbage. There was also, with the higher relation of the mineral supplies to the nitrogen, and with the less forced growth, a higher percentage of mineral matter (pure ash) in the dry substance—7·56 against 6·96 in that of plot 14.

Then as to the comparative composition of the ash in the two cases. The most prominent point of distinction is, that with only half as much soda supplied as nitrate on plot 16, the ash contained much less soda—only 5·11 against 9·32 per cent.; and, with this there was a correspondingly large proportion of potash—32·52 instead of only 28·49 per cent. This was the case notwithstanding the produce was less gramineous, and less stemmy; but, as Table III. (pp. 156–157) shows, the character of development of both the leguminous and the miscellaneous herbage under the influence of liberal potash supply, is such that their ashes contain a high percentage of it.

Again, with the less stemminess, and the less ripeness, of the produce of plot 16 than of that of plot 14, the ash contains rather more lime, and also rather more phosphoric acid; but the percentages of magnesia, sulphuric acid, and chlorine, are almost identical in the two cases. The only other point to notice in the percentage composition of the ashes is, that with the less amount of soda in the ash of the produce of plot 16, there is, as has been observed in other comparable cases, a less amount of silica —18·03 against 20·08 per cent. in the ash of the produce of plot 14; and with this less amount of silica there is rather more carbonic acid—11·05 against 10·14 per cent. Lastly, it is remarkable that with the same supplies of lime, magnesia, potash, phosphoric acid, and sulphuric acid, to each of the two plots, the produce per acre, though one-fifth less in one case than in the other, contained almost identically the same amount of each of these constituents; whilst, with only half as much nitrate of soda applied on plot 16, the produce per acre contained only half as much soda. There is here an indication, therefore, that the soda found in the produce had been taken up as nitrate of soda.

The remaining illustrations which Table VII. affords, further bring to view very strikingly the direct influence of the supplies available within the soil, on both the botanical and the chemical composition of the produce.

The first of these to consider are those obtained on plot 10. This plot received, throughout the whole period to which the results given in Table VII. refer, the same quantity of nitrogen as ammonium-salts as plot 9. It also received, during the first 6 of the 18 years, the same complex mineral manure, containing salts of potash, soda, and magnesia, and superphosphate of lime. But, during the succeeding 12 years, the potash was omitted from the mixture, and an increased amount of soda was applied instead.*

* Plot 10 also received sawdust (but practically without effect) first 7 years, 1856–62.

The effect of the exclusion of the potash from the manure was greatly to reduce the amount of produce, of both the gramineous and the non-gramineous herbage; to reduce the number of species developed, and especially the number of grasses contributing more than 1 per cent. to the produce. Further, there was a great reduction in the tendency to stem-formation; the herbage being more leafy and dark green, and remaining backward and green, when plot 9, with the potash, was ripe enough for cutting.

With the less amount, and more leafy, and immature condition, of the produce, the percentage of nitrogen in the dry substance is much higher, namely 1·84, against only 1·43 during the first 6 years, and only 1·55 in that of plot 9 (over the 18 years), with the continuous supply of potash. There was, in fact, with the higher percentage of nitrogen in the dry substance of the produce of plot 10, almost identically the same average amount of it taken up per acre as on plot 9. That is to say, the nitrogen was taken up, and the chlorophyll was formed, but the assimilation of carbon, and carbohydrate formation, were restricted, in defect of sufficient potash. There was, on the other hand, after the cessation of the application of potash, a much lower percentage of total mineral matter (pure ash) in the dry substance—namely only 6·32 instead of 8·35 per cent. during the 6 years of the application of potash

The change in the composition of the ash itself is more striking still. Thus, during the 6 years of the application of the potash, the ash contained 29·51 per cent. of it, but over the 12 years of the exclusion of the potash from the manure, it contained only 16·96 per cent. On the other hand, during the 6 years of the potash supply, the ash contained only 5·77 per cent. of soda, but during the next 12 years it contained 14·97 per cent., or about twice-and-a-half as much; and, with the deficiency of potash supply, there were somewhat higher percentages of both lime and magnesia —of lime 9·80 against 9·21 previously, and of magnesia 5·42 against 3·16 previously. There were also higher percentages of both phosphoric acid and sulphuric acid over the later period; but less of both chlorine and carbonic acid. Lastly, it is to be observed that there is not here a higher percentage of silica, with the much higher percentage of soda, as has been seen in other cases.

In reference to the very great reduction in the percentage of potash in the ash after the cessation of the application of it in the manure, it may be observed that it was reduced to about the same amount as was found in the ashes of the produce where no potash had been applied at all. Thus, against 16·96 per cent. of potash in the ash of the produce of plot 10 over the 12 years when it was not supplied, there was—with ammonium-salts alone (plot 5) 17·74 per cent., with nitrate of soda alone (plot 15) 14·53 per cent., with half the quantity of nitrate alone (plot 17) 16·93 per cent., and with ammonium-salts and superphosphate (plot 4–2) 15·80 per cent. There is, nevertheless, evidence that will be considered in some detail in a subsequent Section, which it is hoped will soon follow, that there remained some available residue of the previously applied potash in the soil after the cessation of the application.

Table VIII. (pp. 198–199) shows, however, that during the six years of the application of the potash there was an average of 126·9 lb. of potash removed in the crop per acre per annum, but that during the 12 years of the exclusion of potash from the manure, there was only 43·2 lb. annually removed in the crop, or little more than one-third as much. On the other hand, the average amount of soda in the annual crops per acre was raised from 24·8 lb. over the 6 years of the application of the potash, to 38·2 lb. over the 12 of the discontinuance; but the silica was reduced from 92·2 lb. over the 6 years, to only 50·2 lb. over the succeeding 12 years.

The interest of the variations in the percentage of the ash, and in the amount of constituents found in the produce per acre, due to variations in the supply, is of course in the fact, that the differences are associated with differences in the botanical character, and in the organic composition, of the produce—that is in the description of plants encouraged, and in the character of their development; whilst, upon these depends the value of the produce. The cessation of the application of the potash was not only followed by less amounts of total produce, as already stated, but the produce became more exclusively gramineous, only 9 instead of 13 grasses contributed more than 1 per cent. to the produce; and, of the 9, *Festuca ovina* yielded over 20 per cent., or much more than previously; and *Agrostis vulgaris*, *Avena elatior*, and *Poa pratensis*, also became more prominent; whilst *Dactylis glomerata* and others were less so. But, independently of the description of plants encouraged, it was the leafy, dark green, and immature condition of the herbage, to which the deterioration of the produce was characteristically due. In fact, in defect of a sufficient supply of potash, the merely vegetative, as distinguished from the reproductive and maturing tendencies of growth, predominated; the result being a relatively deficient production of carbohydrates.

Plot 6.—*With Mixed Mineral Manure, after Ammonium-salts.*

The last illustrations given in Table VII., relate to plot 6, and they are as striking as those relating to plot 10, but they bring out very different points. Plot 6 received, over the first 7 years ammonium-salts and sawdust, and over the next 6 years ammonium-salts alone, that is ammonium-salts 13 years in succession, 1856–1868 inclusive, in quantity equal to that applied to plot 5 without, and to plots 9 and 10 with, mineral manures. The application of the ammonium-salts was then discontinued; and the complex mineral manure, including potash, the same as that used on plots 7, 9, and others, was applied instead.

One object in view in making the change was to ascertain whether, under the influence of the full mineral supply, any material amount of the previously unrecovered nitrogen of the ammonium-salts would now be recovered; and another was to see whether the leguminous herbage, which had been practically excluded under the influence of the ammonium-salts, would regain prominence under the influence of the complex mineral manure including potash. The result was, that but little of the

previously unrecovered supplied nitrogen was now recovered, but that the leguminous herbage did gradually regain prominence under the influence of the potash supply.

Under the influence of the ammonium-salts, not only had the leguminous herbage almost entirely disappeared, but some weeds, especially the *Rumex acetosa*, and in a less degree the *Conopodium denudatum*, had acquired very undue prominence, thus reducing the proportion of the gramineous herbage. The poor surface-rooting *Festuca ovina*, and the *Agrostis vulgaris*, were by far the most prominent among the grasses; whilst the whole of the herbage, and especially the gramineous, was very leafy and dark green, there being very little tendency to stem-formation or to maturation.

After the substitution of the complex mineral manure for the ammonium-salts, a great change in the character of the herbage soon manifested itself. Not only did leguminous growth, especially that of the *Lathyrus pratensis*, gradually increase, but the *Rumex acetosa* and the *Conopodium denudatum* greatly diminished; the result being a corresponding increase in the proportion of the gramineous herbage. It is true that much the same grasses characterised the produce as previously; but now, under the influence of the mineral manure containing potash, they showed great tendency to stem-formation, and accordingly lost the dark green leafy character, and matured well. This change in the character of growth was specially marked in the case of *Festuca ovina*, which, after some years, yielded an average of nearly 35 per cent. to the total produce, whilst previously it had contributed an average of under 20 per cent., and the increased quantity was mainly due to increased stemminess and ripeness; that is to more carbon-assimilation in proportion to the nitrogen, and an increase in the formation of non-nitrogenous compounds, under the influence of the potash.

Coincidently with these great changes in the character of growth, the chemical composition also changed in a very marked degree. Thus, under the influence of the ammonium-salts, the dark green, leafy, and immature produce, contained 2·10 per cent. of nitrogen in its dry substance, but the more gramineous, more stemmy, and riper herbage grown under the influence of the purely mineral manure including potash contained, over the immediately succeeding five years, only 1·46 per cent. of nitrogen in its dry substance. The percentage of total mineral matter (pure ash), in the dry substance was, however, not very different in the two cases—being 6·29 under the influence of the ammonium-salts, and the consequent relative deficiency of mineral supply, and only 6·56 with the exclusive and full mineral supply, under the influence of which much more non-nitrogenous organic matter was formed in relation to both the nitrogen and the mineral matter of the crop.

Then as to the difference in the detailed mineral composition of the produce, under the two very different conditions both as to supply and as to the description of plants encouraged, and the character of growth, of the herbage accordingly. The first point to notice is, that over the 13 years of the application of

ammonium-salts, the ash contained only 18·22 per cent. of potash, whilst over the next 5 years, with the full mineral supply including potash, it contained 34·29 per cent., or not far from twice as much. Further, with the increase in the percentage of potash in the ash, there is a reduction in that of soda from 8·63 to 2·64 ; and this is the case notwithstanding that soda was now supplied in the complex mineral manure, but had not been previously. There is, at the same time, a reduction in the percentage of lime from 14·38 to 9·25, and in that of magnesia from 5·66 to 3·62. On the other hand, with the application of superphosphate in the mineral manure, there is an increase in the percentage of phosphoric acid in the ash from 5·99 to 8·75 ; and with this, and the cessation of the application of ammonium-sulphate and chloride, there is a reduction in the percentage of sulphuric acid from 7·87 to 7·09, and of chlorine from 11·72 to 6·18 per cent. But, with the increase in the leguminous herbage, and a reduction in the percentage of silica, there is an increase in the percentage of carbonic acid from 6·91 to 9·82. The reduction in the percentage of silica is from 21·36 to 17·95 ; this being associated with a reduction in the percentage of soda, and with an increased stemminess of the grasses—implying more carbohydrate formation.

It is of interest to observe, that a comparison of the composition of the ash of the produce of this plot over the 13 years, with that of plot 5 with the same application of ammonium-salts over the whole period of 18 years, shows the two to be nearly identical. Again, a comparison of the composition of the ash of the produce of plot 6 over the 5 years of the exclusive application of the mineral manure containing potash, with that of plot 7 which received the same manure throughout the 18 years, shows a very great similarity ; whilst in subsequent years the approach to identity in composition has been nearer still.

Thus, as in the case of plot 10 there was, with the exclusion of potash from the manure a reduction in the amount of produce (see Table VIII.), and a deterioration in its character, and coincidently a great reduction in the percentage of potash in the ash, and an increase in that of soda and other bases, so now, in the case of plot 6, with the substitution of a mineral manure containing potash for ammonium-salts, there is even an increase in the amount of produce, an improvement in the description of the herbage, and in the character of its development, and coincidently a great increase in the percentage of potash in the ash, and a great decrease in that of soda and other bases.

But the direct influence of the supply within the soil on the composition of the crop, is perhaps still more strikingly illustrated by the results given in Table VIII. It has been already said that, with the cessation of the application of potash to plot 10, the amount of it in the crop per acre declined from an average of 126·9 lb. to only 43·2 lb. per annum ; and now, on plot 6 the application of potash raises the amount of it in the crop, even within 5 years, from 32·7 to 68·3 lb. per acre per annum ; and there can be no doubt that the amount has increased in subsequent

years. Further, with the increase in the amount of potash in the annual crop, the amount of lime taken up and retained was reduced from 25·8 to 18·4 lb.; that of magnesia from 10·2 to 7·2 lb., and that of soda from 15·5 to 5·3 lb. There was this reduction in the amount of lime, magnesia, and soda, notwithstanding that all were now supplied, but had not been so previously.

Thus then, although the results afford clear evidence of the direct influence of available supply on the composition of the produce, and that this influence is, to a certain extent, manifest even in the case of the relatively less prominent or less functionally important constituents, yet when those which have a more marked effect in determining the character of development, such as potash for example, which tends to stem-formation and to maturation, are in relative prominence, other constituents which are more associated with opposite characters of growth may, even though liberally supplied, be found in actually reduced amount in the crop.

The amount of the different Constituents in the Crops per acre.

Throughout the foregoing discussion, reference has frequently been incidentally made to some of the results given in Table VIII. (p. 198–199); which shows the amounts of dry matter, of total mineral matter (pure ash), of nitrogen, and of most of the ash-constituents, as experimentally determined; also the calculated amounts of the nitrogenous, the non-nitrogenous, and the total organic substance, in the average produce per acre per annum over the 18 years 1856–'73, under the different conditions of manuring. It should be added, that the total organic substance is calculated by deducting the mineral matter from the total dry substance, the nitrogenous substance by multiplying the nitrogen by 6·3, and the non-nitrogenous by deducting the so-calculated nitrogenous from the total organic substance. It is obvious that such estimates cannot claim accuracy, but the results are approximations to the truth, and as such are useful in their general comparative indications. The question of the condition of the nitrogenous substance in the herbage under different conditions of growth, and some collateral points, will be considered independently in a subsequent Section. Bearing in mind the above explanations, it will be well before concluding this Section relating to the composition of the first crops of the first 18 years, to refer in more detail to the results given in the table; and it will be convenient to consider those relating to the different plots, as arranged in the four groups as in Tables I and VII, representing respectively, very characteristically different conditions as to manuring.

The amounts of total dry matter as recorded in the first column of the table, give approximately a view of the relative amounts of produce; but those of the different constituents are of more interest to consider.

The total Mineral Matter (pure ash):—The amount of total mineral matter in the crops of the first group of plots ranged from an average of 144 lb. per acre per annum over the 18 years on plot 3 without manure; to 271 lb. on plot 2 with farm-

TABLE VIII.—The Mixed Herbage of Permanent Grass-land at Rothamsted—First different Manures. Averages for

Plots.	Description of Manure (commencing 1856).	Constituents per acre. Dry Matter.	Mineral Matter (pure ash).	Nitrogen.	Nitrogenous substance.
	GROUP 1—Plots without Manure, or with Farmyard Manure.				
		lb.	lb.	lb.	lb.
3	Unmanured continuously	2,053	144	34	214
2	Farmyard Manure 8 years, Unmanured 10 years	3,607	271	50	314
1	Farmyard Manure, and Ammonium-salts (= 43 lb. Nitrogen) 8 years; Ammonium-salts alone (= 43 lb. Nitrogen) 10 years	4,166	299	61	383
	GROUP 2—Plots with Nitrogenous Manures alone.				
5	Ammonium-salts (= 86 lb. Nitrogen)	2,567	155	55	347
15*	Nitrate of Soda (= 86 lb. Nitrogen)	3,375	231	64	402
17*	Nitrate of Soda (= 43 lb. Nitrogen)	3,233	227	56	355
	GROUP 3—Plots with Mineral Manures alone.				
7	Mixed Mineral Manure including Potash	3,320	266	58	363
4-1*	Superphosphate of Lime	2,140	155	35	218
8†	Mixed Mineral Manure: 6 years with Potash	3,381	286	61	384
	Mixed Mineral Manure: 12 years without Potash	2,654	196	42	263
	Mixed Mineral Manure: Total period, 18 years	2,896	226	48	304
	GROUP 4—Plots with Nitrogenous and Mineral Manures together.				
9	Mixed Mineral Manure, and Ammonium-salts (= 86 lb. Nitrogen)	4,812	348	74	468
13	Mixed Mineral Manure, Amm.-salts (= 86 lb. N.), and cut Wheat Straw	5,269	393	83	523
11-1	Mixed Mineral Manure, and Ammonium-salts (= 158 lb. Nitrogen)	5,479	398	106	667
11-2	Mixed Mineral Manure, Ammonium-salts (= 158 lb. N.); and Silicates 1862 and since	5,785	424	109	688
14‡	Mixed Mineral Manure, and Nitrate of Soda (= 86 lb. Nitrogen)	5,358	373	70	439
16‡	Mixed Mineral Manure, and Nitrate of Soda (= 43 lb. Nitrogen)	4,438	336	65	407
4-2*	Superphosphate, and Ammonium-salts (= 86 lb. Nitrogen)	3,046	192	58	367
10†	Mix. Min. Man., and Amm.-salts (= 86 lb. N.): 6 years with Potash	5,152	430	73	461
	Mix. Min. Man., and Amm.-salts (= 86 lb. N.): 12 years without Potash	4,034	255	74	465
	Mix. Min. Man., and Amm.-salts (= 86 lb. N.): Total period, 18 years	4,407	313	74	464
	PLOT 6.				
6†	Ammonium-salts alone (= 86 lb. Nitrogen) 13 years, 1856–'68	2,854	180	59	372
	Mixed Mineral Manure alone, including Potash, 5 years, 1869–'73	3,038	199	44	278
	Total period, 18 years	2,906	185	55	347

* Commenced in 1859; 1856-8 sawdust only, but practically without effect.

† Also sawdust (but practically without effect) first 7 years 1856-62.

‡ Commenced in 1858.

Crops. Constituents in the crops per acre per annum, without Manure, and by 18 (or fewer) years, 1856–1873.

Constituents per acre (continued).									
Non-nitrogenous substance.	Dry Organic Matter.	Lime.	Magnesia.	Potash.	Soda.	Phosphoric acid.	Sulphuric acid.	Silica.	Plots.
Group 1—Plots without Manure, or with Farmyard Manure (continued).									
lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	
1,695	1,909	24·9	6·6	27·6	9·9	7·6	8·6	33·3	3
3,022	3,336	30·9	10·2	73·7	11·0	18·4	12·8	72·9	2
3,484	3,867	36·0	12·5	74·9	19·3	20·4	16·2	71·2	1
Group 2—Plots with Nitrogenous Manures alone (continued).									
2,065	2,412	21·7	9·5	27·4	13·1	9·9	12·7	34·2	5
2,742	3,144	24·2	9·7	33·5	41·6	12·3	12·7	49·4	15
2,651	3,006	27·3	9·6	38·4	29·8	11·6	13·0	52·9	17
Group 3—Plots with Mineral Manures alone (continued).									
2,691	3,054	31·7	9·3	92·1	4·1	21·1	18·0	40·9	7
1,767	1,985	25·0	7·0	28·9	11·8	13·0	12·0	33·3	4–1
2,711	3,095	36·5	9·2	87·6	8·9	20·0	21·0	49·9	}
2,195	2,458	24·3	8·3	45·7	13·9	18·2	16·0	40·7	} 8
2,366	2,670	28·4	8·6	59·7	12·2	18·8	17·7	43·8	}
Group 4—Plots with Nitrogenous and Mineral Manures together (continued).									
3,996	4,464	28·8	11·9	124·0	13·5	27·7	20·1	57·6	9
4,353	4,876	30·0	13·1	144·2	14·5	30·9	22·3	64·6	13
4,414	5,081	28·7	14·8	135·9	24·4	29·9	22·0	65·5	11–1
4,673	5,361	30·1	15·7	142·7	27·3	31·7	22·5	71·7	11–2
4,546	4,985	30·8	12·5	106·2	34·8	27·4	25·9	74·9	14
3,695	4,102	30·1	11·0	109·1	17·1	27·5	22·8	60·5	6
2,487	2,854	28·4	11·8	31·5	17·7	20·7	14·4	39·6	4–2
4,261	4,722	39·6	13·6	126·9	24·8	29·4	26·6	92·2	}
3,314	3,779	25·0	13·8	43·2	38·2	26·6	17·2	50·2	} 10
3,630	4,094	29·9	13·7	71·1	33·7	27·5	20·4	64·2	}
Plot 6.									
2,302	2,674	25·8	10·2	32·7	15·5	10·8	14·1	38·3	}
2,561	2,839	18·4	7·2	68·3	5·3	17·4	14·1	35·8	} 6
2,374	2,721	23·8	9·3	42·6	12·7	12·6	14·1	37·6	}

yard manure for 8 years and afterwards unmanured ; and to 299 lb. on plot 1 with farmyard manure and 43 lb. of nitrogen as ammonium-salts for 8 years, and the ammonium-salts alone each year afterwards.

In the second group, with nitrogenous manures alone, the amount of total mineral matter annually removed in the crops, ranged from only 155 lb. on plot 5 with ammonium-salts alone (that is not much more than without manure) ; to 231 lb. on plot 15 with the same quantity of nitrogen but as nitrate of soda ; and to 227 lb. on plot 17 with half the quantity of nitrogen applied as nitrate of soda.

In the third group, with mineral manures alone, the average yield of total mineral matter in the crops ranged from only 155 lb. on plot 4–1, with superphosphate of lime alone ; to 266 lb. on plot 7, with the complex mineral manure including besides superphosphate, potash, soda, and magnesia ; and to 226 lb. on plot 8, with the same complex mineral manure, including potash for 6 years, but excluding it for 12 years ; the amounts being 286 lb. over the 6 years, but only 196 over the subsequent 12 years.

In the fourth group, with mineral and nitrogenous manures used together, the average annual amount of total mineral matter in the crops ranged from 192 lb. on plot 4–2, with ammonium-salts and superphosphate, without potash, soda, or magnesia ; to 348 lb. on plot 9 with the same quantity of ammonium-salts, but with the complex mineral manure, including besides superphosphate, potash, soda, and magnesia ; to 393 lb. on plot 13, with the same amount of ammonium-salts and mineral manure as plot 9, but with cut wheat straw each year in addition ; to 373 lb. on plot 14, with the same quantity of nitrogen as plot 9, but as nitrate of soda, and the same complex mineral manure ; to 336 lb. on plot 16 with the same mineral manure, but with only half the quantity of nitrate of soda as plot 14 ; to 398 lb. on plot 11-1 with an excessive amount of nitrogen as ammonium-salts, and the full mineral manure ; and to 424 lb. on plot 11–2 with the same excessive amount of ammonium-salts, and the same complex mineral manure as on plot 11–1, but with artificial silicates in addition. Lastly, on plot 10, with ammonium-salts every year, and the mineral manure including potash for 6 years, but excluding the potash afterwards, the average amount of mineral matter in the crop over the 18 years was 313 lb. ; the amounts being 430 lb. over the 6 years with, but only 255 lb. over the 12 years without potash.

The whole series of plots included in the four groups shows, therefore, a range in the average annual amount of mineral matter in the crops from 144 lb. without manure (plot 3) ; to only 155 lb. with ammonium-salts alone (plot 5) ; to 266 lb. with the complex mineral manure alone (plot 7) ; to 348 lb. with the ammonium-salts and complex mineral manure together (plot 9) ; and to 398 and 424 lb. with an excessive amount of ammonium-salts, and full mineral manure (plots 11–1 and 11–2).

Then as to the individual mineral constituents.

Potash :—The average amount per acre per annum of potash, which so materially

determines both the description of plants encouraged, and the character of their development, ranged among the four groups of plots, from only 27·6 lb. in the crops without manure (plot 3), and 27·4 with ammonium-salts alone (plot 5); to 33·5 and 38·4 lb., with nitrate of soda alone (plots 15 and 17)—the nitrate, from its ready solubility and rapid distribution within the soil, inducing a more extended root-range of the plants, and so increasing their command of the potash of the soil and subsoil, the soda liberated from the nitrate also probably aiding the liberation of the soil-potash; to 92·1 lb. where mineral manure including potash, but without nitrogen, was applied (plot 7); and finally to a maximum of about 140 lb. where nitrogen and mineral manures including potash, were used together (plots 13, 11–1, and 11–2).

Soda:—The amount of soda in the crops per acre, though on a much lower level than that of potash, also varied very considerably according to the manuring and the character of growth;—from as little as 4·1 lb. on plot 7 where it was applied, but in conjunction with a liberal supply of potash; to 9·9 lb. on plot 3 without any manure, to 13·1 lb. on plot 5 with ammonium-salts alone, and consequent great exhaustion of potash; to as much as 41·6 lb. on plot 15 with soda supplied in nitrate of soda alone, and again consequent great exhaustion of potash; and to 34·8 lb. on plot 14, with the same amount of nitrate of soda as plot 15, but with full mineral manure including potash in addition.

Lime:—Among the plots within the four groups, the annual amount in the crops per acre of lime, which is largely soil-supplied, varied comparatively little—ranging only from 24·9 lb. on plot 3 without any manure, to from 25·0 to 31·7 lb. where it was applied in the one case (4–1) in superphosphate of lime alone, and in the other in conjunction with potash, soda, and magnesia (plot 7); but going up to 36·5 lb. on plot 8 over the first 6 years with the same manure including potash as plot 7—the produce of both plots containing high percentages of leguminous herbage. In the fourth group, with nitrogenous as well as mineral manure, these amounts are in no case reached, excepting in the first 6 years of plot 10. Lastly, the amounts of 30·9 lb., and 36·0 lb. are reached on plots 2 and 1, where it had been applied during the first 8 years in farmyard manure—in the one case without, and in the other with, ammonium-salts in addition.

Magnesia:—The quantity of magnesia in the crops is on a much lower level than that of lime, but varied in a greater degree according to the conditions of manuring and of growth. The lowest amount was only 6·6 lb. on plot 3 without manure, and 7·0 lb. on plot 4–1 with superphosphate of lime alone; and the highest was only 15·7 lb. on plot 11–2, with the excessive amount of ammonium-salts, and a full mineral manure including magnesia—and also with very much larger crops.

Phosphoric acid:—The amount of phosphoric acid in the crops is seen to be dependent on the supplies of it by manure, but greatly also on the supply of other constituents, and the character of growth thereby induced. It varied from only 7·6 lb. on plot 3 without manure, to nearly or over 30 lb. where it was liberally

supplied in conjunction with nitrogenous and potash manures, under which conditions there was luxuriance of growth, coincident activity of root-action and of mineral collection and large amounts of produce.

Sulphuric acid:—The amount of sulphuric acid found in the crops, although not independent of the amount of it supplied in manure, was at the same time much influenced by the associated supplies of other constituents which increase the luxuriance, and with this the range and activity of the roots of the plants, and the amount of produce. The smallest amount was 8·6 lb. in the crop of plot 3 without manure; and it was increased by the residue of farmyard manure. There was about 1½ time as much as without manure, in the crops of the second group with nitrogenous manures alone; rather more in those of the third group with exclusively mineral manures in which it was supplied; and more still in those of the fourth group with mineral and nitrogenous manures together, in which it was liberally supplied, and which induced the greatest luxuriance, and produced the heaviest crops.

Silica:—The amounts of silica found in the crops per acre ranged within the plots of the four groups from 33·3 lb. on plot 3 without manure, to 72·9 and 71·2 lb. on plots 2 and 1, where farmyard manure had been annually applied during the first 8 of the 18 years, but not since. The influence for many years, of a store of silica in a slowly available condition, as in the residue of farmyard manure, is here clearly manifest. With ammonium-salts alone (plot 5), though the amount of gramineous herbage was increased, there was only 34·2 lb. of silica in the crops, that is scarcely any more than without manure; but with nitrate of soda alone, there was a considerable increase—49·4, and 52·9 lb. With the mineral manures alone (group 3), there was less increase in the amount of silica than with the nitrate of soda alone; but more on plots 7 and 8, where soda was applied, than on plot 4–1 where it was not. On plot 9 with ammonium-salts and the complex mineral manure, but no silica, the average amount of it in the crops was 57·6 lb.; and on plot 13 with the same nitrogenous and mineral manure as on plot 9, but with cut wheat-straw in addition, the amount of silica was raised to 64·6 lb.; on plot 11–1, with the same mineral manures but an increased amount of ammonium-salts, the quantity was 65·5 lb.; but on plot 11–2 with artificial silicates added, it was 71·7 lb. Lastly, on plot 14, with the complex mineral manure and nitrate of soda, the amount of silica in the crops was 74·9 lb.*

Thus, excepting in the case of the plots where there was a residue of farmyard manure (and slightly on Plot 13 where wheat straw had been used), the amount of silica in the crops was obviously but little dependent on direct supply of it; but was much more so on the description of plants developed and on the character

* The highest amount of silica in the produce of any plot, was 92 lb. in that of plot 10, over the first 6 years when the manuring was the same as that of plot 9, excepting that it had sawdust in addition.

of their development under the influence of other conditions; and it is to be observed, as would be expected, that in all the cases of high amounts of silica in the crops, it was where the gramineous herbage was forced into prominence under the influence of liberal supplies of both nitrogen and mineral constituents. It is, however, obvious that there was more silica where the nitrogen was given as nitrate of soda, than where it was applied in corresponding amount in ammonium-salts. There is also, in the crops of the third group, with mineral manure alone, more silica where soda was included than where it was not. In reference to this point it will be remembered that, in the detailed discussion of the percentage composition of the ashes, attention was several times called to the fact that, in comparable cases, an increased percentage of silica was generally associated with an increased percentage of soda.

Nitrogen:—Of nitrogen, the average annual amount in the crops ranged, in the first group, from 34 lb. on plot 3 without any manure, to 50 lb. on plot 2, where farmyard manure had been applied during the first 8 of the 18 years, and to 61 lb. on plot 1, where besides the residue of farmyard manure previously applied, 43 lb. of nitrogen were annually supplied as ammonium-salts.

In the second group, to which nitrogenous manures alone were applied, the annual yield of nitrogen in the first crops was from 55 lb. on plot 5 with 86 lb. of nitrogen as ammonium-salts; to 64 lb. on plot 15 with the same amount of nitrogen applied but as nitrate of soda; and to 56 lb. on plot 17 with only half the quantity (43 lb.) annually supplied as nitrate of soda.

To the plots of the third group, mineral manure was annually applied, but no nitrogen; and the annual yield of nitrogen in the first crops was 35 lb. on plot 4–1 with superphosphate of lime alone, 58 lb. on plot 7 with the full mineral manure including potash, by which the highly nitrogenous leguminous herbage was much encouraged, and the grasses became stemmy and matured. Part of the increased amount of nitrogen in the crops under the influence of the mineral manure including potash was, as shown by analyses of the surface-soil, derived from the stores of the soil itself; and part by fixation, as shown by the presence of nodules on the roots of the leguminous plants. The yield was, however, compared with that on plot 7, reduced to an average of only 48 lb. over the 18 years on plot 8, from the manuring of which potash had been excluded during the last 12 of the 18 years. The reduction was from 61 lb. over the 6 years with potash, to 42 lb. over the 12 years without it, and it was associated with a great reduction in the amount of leguminous herbage, and a great reduction in the amount and character of the grasses, but an increase in the amount of miscellaneous herbage.

In the fourth group, where the nitrogenous and mineral manures were used together, the average annual yield of nitrogen in the crops was 74 lb. on plot 9, with 86 lb. supplied per acre per annum as ammonium-salts; 70 lb. on plot 14, with the same amount applied, but as nitrate of soda; 65 lb. on plot 16 with half the quantity as nitrate of soda; and 106 and 109 lb. on plots 11–1 and 11–2, where the

excessive amount of 158 lb. of nitrogen was on the average annually supplied. It should be added, that to each of the above plots the same complex mineral manure was annually applied; excepting that on plot 11–2 artificial silicate was supplied in addition. On plot 4–2, on the other hand, with ammonium-salts and superphosphate, but no potash, soda, or magnesia, and accordingly by far the smallest produce within the group, scarcely any leguminous herbage, and characteristically dark green and immature leafy produce, the average annual yield of nitrogen was also the lowest within the group, namely, 58 lb. There was, therefore, three times as much nitrogen in the crop over a given area where it was very abundantly supplied, as where no manure was used; and there was nearly twice as much as where the complex mineral manure was used alone.

Looking at the results from another point of view, it is of interest to notice that where 86 lb. of nitrogen were annually applied as ammonium-salts alone (plot 5), the average amount of nitrogen in the first crops was 55 lb., but where the same amount of ammonium-salts was used in conjunction with the complex mineral manure including potash (plot 9), the amount of nitrogen in the produce was 74 lb. Again, when the same amount of nitrogen was applied as nitrate of soda (plot 15), the annual yield of nitrogen in the crop was 64 lb.; but when the nitrate was used with the complex mineral manure including potash (plot 14), the yield in the crop was 70 lb.

Lastly, the figures quoted show, that where nitrogen was applied as manure, a large amount of that supplied remained unrecovered as increased yield in the crop.

The Non-nitrogenous substance:—The mode of estimating the non-nitrogenous substance has been explained, and it is admitted that the results are only approximations to the truth. Still, they have considerable significance. Thus, when ammonium-salts alone supplying 86 lb. of nitrogen per acre per annum were used (plot 5), the estimated annual yield of non-nitrogenous substance in the removed crop was 2065 lb. When the same amount of ammonium-salts was used with superphosphate (plot 4–2), the yield was 2487 lb., or 422 lb. more; but when used with superphosphate, and potash, soda, and magnesia (plot 9), the yield was 3996 lb., showing therefore a further increase of 1509 lb.; or a total increase of 1931 lb. compared with the yield by the ammonium-salts alone. Again, when the same amount of nitrogen was applied as nitrate of soda (plot 15), the yield of non-nitrogenous substance was 2742 lb.; but when the same amount of nitrate was used with the mixed mineral manure, including potash (plot 14), it was 4546 lb., or 1804 lb. more. Lastly, when the ammonium-salts were applied with the mixed mineral manure including potash, over 6 years (plot 10), the annual yield of non-nitrogenous substance was 4261 lb.; but when over the next 12 years potash was excluded from the manure, the yield was only 3314 lb.—or 947 lb. less.

There can be no doubt that the luxuriance, or vegetative activity, is intimately associated with the amount of nitrogen available and taken up. Further, it may be stated that chlorophyll-formation to a great extent follows nitrogen-assimilation.

But the results as to the amount of non-nitrogenous substance produced, clearly indicate that the nitrogen being taken up, and the chlorophyll formed, the carbon-assimilation, and the carbohydrate-formation, depend essentially on the amounts of potash available.

In connection with the foregoing results and conclusions, it may be stated as a matter of fact, that in practical agriculture artificial nitrogenous manures are chiefly used for crops containing a comparatively low percentage of nitrogen in their dry substance, and yielding comparatively low amounts of nitrogen per acre. Indeed, they are mainly used for the increased production of the non-nitrogenous bodies—the carbohydrates—starch and cellulose in the cereals, starch in potatoes, and sugar in the sugar-cane and in root-crops, for example. And, in the case of the mixed herbage of grass-land, it is seen that, provided the mineral constituents, and especially potash, are abundantly available, a characteristic effect of nitrogenous manures is to increase the production of the non-nitrogenous bodies.

Recurring to the mineral or ash-constituents, the foregoing illustrations relating to the amounts of them found in the annual crops per acre, are seen fully to confirm the conclusions drawn from the detailed consideration of the percentage composition of the ash of the produce of the differently manured plots. Both series of results show, that the mineral composition of the mixed herbage is very directly dependent on the supplies available to the plant within the soil. Indeed, when it is considered that the mixed herbage of permanent grass-land, includes plants of very various root-range and root-habit, and that some of them vegetate more or less almost the year round, it is not surprising to find that the composition of the produce is upon the whole a somewhat close reflection of the available supplies within the range of the roots. It is, in fact, much more so than in the case of individual crops grown separately. Within certain limits, this is the case even with the constituents of, so to speak, less functional importance than those which more obviously determine the description of plants encouraged, and the character of their development. It is at the same time obvious, that when the more functionally important constituents are available in relative abundance, those which are of less importance in this respect, are taken up and retained in less amount than they otherwise would be; the result being determined in great measure by the character of growth induced.

For example, if potash be liberally available, the produce is much more stemmy, and the amount of soda, of lime, and to some extent of magnesia also, will be less relatively to the potash. In defect of sufficient potash on the other hand, more of soda, or of lime, or of both, will be taken up and retained; but the herbage will at the same time be more leafy and immature. That is to say, the constituents are not mutually replaceable in the processes of growth, but accordingly as the one or the other predominates, so will the product of growth be different. In like manner, in defect of a sufficiency of phosphoric acid, the amount of sulphuric acid, or of chlorine, or of both, may be greater in relation to it, but at the same time the results of growth will be different.

Summary and General Conclusions.

The results show that the chemical composition of the mixed herbage is very directly dependent, not only on the supplies within the soil, and on the seasons, but also very prominently on the description of plants encouraged, and on the character of their development. Hence it was essential to a proper interpretation of the variations in the chemical composition under different conditions as to manuring, &c., carefully to consider the differences in the botanical composition, and in the characters of growth, with which the differences in the chemical composition were associated. Accordingly, a summary Table of the botanical results was given and discussed.

The consideration of the chemical composition of the mixed produce under the different conditions of growth, included that of the results of a large number of complete analyses of the ashes of the separated, or of the mixed herbage. Attention was, therefore, called to the state of existing knowledge as to the *rôle* or function in vegetation, of the individual constituents found in the ashes of plants; and it was seen to be very imperfect. Further, in calculating the percentage composition of the "*pure ash*," the plan usually adopted was to exclude not only the sand and charcoal, but also the carbonic acid. Any special importance of carbonic acid in plant-ashes had therefore been generally ignored. It was considered, however, that the presence and the amount of carbonic acid associated with the fixed constituents in plant-ashes, was a point of great significance. Accordingly, the conditions under which carbonic acid was determined in ashes, and the results obtained, were considered in some detail.

To illustrate the connection between the botanical composition and the character of growth of the crops, and their mineral or ash-composition, results relating to the separated gramineous, the separated leguminous, and the separated "miscellaneous" herbage of the mixed produce, grown without manure and by different manures, were first given and discussed.

To obtain more definite evidence illustrating the connection between the character and stage of growth, and the composition of the products--especially the ash-composition—results relating to the bean-plant taken at successive periods of growth, and also to the first, second, and third, crops of red clover, were next considered.

Lastly, in further illustration, results as to the nitrogen and the ash-composition of crops of three different natural Orders—wheat representing the Gramineæ, Swedish turnips the Cruciferæ, and beans and red clover the Leguminosæ—were given.

The general result was, that there were very characteristic differences in the composition of the ashes of different crops, according to the amounts of nitrogen they assimilated. Red clover, for example, yields large amounts of nitrogen over a given area, part of which is due to fixation, but much is certainly taken up as nitrates from the soil; and the results show that the greater the amount of nitrogen assimi-

lated, the more is the ash characterised by containing fixed base in combination with carbonic acid; presumably representing organic acid in the vegetable substance before incineration.

The conclusion was that, independently of any specially physiological function of the bases, such as that of potash in connection with the formation of carbohydrates, for example, their office was prominently also that of *carriers of nitric acid*, and that when the nitrogen had been assimilated the base was left as a residue in combination with organic acid—which, according to the character of the plant, was represented more or less completely by carbonic acid in the ash.

Further, existing knowledge—as to the condition in which nitrogen is found in soil waters, as to the action of nitrates used as manures, as to the presence of nitrates in still-growing plants, and as to the connection between the nitrogen assimilated and the composition of the ash as has been illustrated—points to the conclusion that, at any rate a large amount of the nitrogen of the chlorophyllous vegetation on the earth's surface is derived from nitrates; whilst, so far as this is the case, the *raison d'être* of much of the fixed base found in the ashes of plants would seem to be clearly indicated.

The foregoing results and conclusions were found to afford material aid in the interpretation of the differences in the chemical composition of the mixed herbage of the differently manured plots which was next considered—so far as the first crops over the first eighteen years were concerned.

For the purposes of the illustrations, the differently manured plots were arranged in four groups as follows:—1. Plots without manure or with farmyard manure. 2. Plots with nitrogenous manures alone. 3. Plots with mineral manures alone. 4. Plots with nitrogenous and mineral manures together. Average results for each plot generally for a period of eighteen years, 1856–1873, and including the percentages of nitrogen, crude ash, and pure ash, in the dry substance of the produce—also the percentage composition of the pure ash, were brought together in a table, and discussed in detail.

The close dependence of the chemical composition of the mixed herbage on its botanical composition, and on the character of development of the plants, was throughout illustrated.

It is at the same time shown, that the mineral composition of the mixed herbage is very directly dependent on the supplies available within the soil. Indeed, the composition of the mixed produce was found to be a somewhat close reflection of the supplies available within the range of the roots. It was, in fact, more so than in the case of individual crops grown separately. It is at the same time obvious, that when the more functionally important constituents are available in relative abundance, those which are of less importance in this respect are taken up and retained in less amount than they otherwise would be; the result being determined in great measure by the character of growth induced.

Luxuriance or vegetative activity is intimately associated with the amount of nitrogen available and taken up. Further, chlorophyll-formation to a great extent follows nitrogen-assimilation. But the results relating to the increased amount of non-nitrogenous substance yielded in the mixed herbage under the influence of the various manures, clearly indicate that the nitrogen being taken up, and the chlorophyll formed, the carbon-assimilation, and the carbohydrate-formation, depend essentially on the amounts of potash available.

[There remain to consider the results relating to the composition of the produce of the second 20 years, including in many cases second as well as first crops. Accordingly, the amount of analytical data involved is much greater than that which has so far been dealt with. Thus, besides other material, the number of ash-analyses alone is considerably greater. It is hoped, that the second and concluding Section of the subject of the Chemical Composition of the Mixed herbage will soon follow the present one.]

APPENDIX TABLES I., II., and III.

See pages 209, 210, *et. seq.*

APPENDIX TABLE I.—Results of actual analyses of the ashes of the Mixed Herbage of Grass-land, calculated into percentage, excluding sand, charcoal, and carbonic acid determined in the ash ignited at low red heat, but including carbonic acid determined after treatment of the ash with a solution of ammonium-carbonate and drying at 125°–130° C.

("Mixed-year" samples.)

	Group 1. Plots without Manure, or with Farmyard Manure.								Group 2. Plots with Nitrogenous Manures alone.					
	Unmanured continuously.		Farmyard Manure 8 years 1856–'63; Unmanured since.			Farmyard Manure and 43 lb. N. as Amm.-salts, 8 years 1856–'63; 43 lb. N. as Amm.-salts alone, 1864 and since.			Ammonium-salts =86 lb. Nitrogen.		Nitrate Soda = 86 lb. Nitrogen (1858 and since).		Nitrate Soda = 43 lb. Nitrogen (1858 and since).	
	10 years 1856–1865.	8 years 1866–1873.	8 years 1856–1863.	2 years 1864–1865.	8 years 1866–1873.	8 years 1856–1863.	2 years 1864–1865.	8 years 1866–1873.	10 years 1856–1865.	8 years 1866–1873.	8 years 1858–1865.	8 years 1866–1873.	8 years 1858–1865.	8 years 1866–1873.
	Plot 3.		Plot 2.			Plot 1.			Plot 5.		Plot 15.		Plot 17.	
Ferric oxide	0·63	0·52	0·47	0·35	0·49	0·56	0·28	0·60	0·53	0·62	0·60	0·60	0·84	0·72
Manganese oxide	0·50	0·60	0·22	0·26	0·36	0·31	0·51	0·68	1·04	1·90	0·34	0·32	0·55	0·63
Lime	16·62	18·05	10·52	12·96	11·90	11·34	10·66	13·14	14·60	13·31	11·21	9·74	12·87	11·18
Magnesia	4·46	4·74	3·18	4·15	4·23	3·30	4·19	5·05	5·37	7·17	4·10	4·34	4·23	4·24
Potash	19·12	19·08	30·74	28·32	23·30	29·68	28·72	19·56	17·32	18·27	14·92	14·15	17·55	16·30
Soda	6·90	6·86	2·82	2·47	5·67	3·97	5·61	9·13	9·29	7·46	16·82	19·21	11·26	15·03
Phosphoric acid	5·18	5·31	6·92	6·47	6·72	6·67	6·58	7·06	5·89	7·01	4·76	5·91	5·02	5·22
Sulphuric acid	6·26	5·64	4·76	3·84	4·90	4·99	5·23	5·95	8·02	8·54	6·08	4·96	6·20	5·25
Chlorine	5·82	6·16	8·98	5·35	5·09	12·94	13·20	11·51	12·36	9·65	6·00	6·89	5·92	7·15
Carbonic acid	11·35	13·14	8·12	13·61	9·17	5·62	7·57	4·97	5·88	6·61	15·05	14·11	12·36	13·84
Silica	24·47	21·29	25·29	23·43	29·31	23·54	20·43	24·95	22·49	21·63	21·47	21·33	24·54	22·06
Total	101·31	101·39	102·02	101·21	101·14	102·92	102·98	102·60	102·79	102·17	101·35	101·56	101·34	101·62
Deduct O = Cl.	1·31	1·39	2·02	1·21	1·14	2·92	2·98	2·60	2·79	2·17	1·35	1·56	1·34	1·62
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Determinations and estimates of Carbonic acid. Results calculated to 100 excluding Sand and Charcoal.

1. In ash ignited at low red heat	6·02	8·61	3·83	8·75	4·61	2·47	4·17	1·39	1·34	1·70	9·38	7·25	6·38	6·89
2. In ash after treatment with ammonium-carbonate and drying at 125–130° C.	11·35	13·14	8·12	13·61	9·17	5·62	7·57	4·97	5·88	6·61	15·05	14·11	12·36	13·84
3. Calculated requirement to form neutral salts reckoning all phosphoric acid as tribasic	18·34	19·68	12·79	17·45	15·60	11·46	12·47	13·23	13·35	13·82	19·61	19·01	17·96	18·48

NOTE.—Examination of the figures relating to carbonic acid, given at the foot of the Appendix-Tables I., II., and III., will show that in none of these *mixed herbage ashes* was the amount found after treatment with a solution of ammonium-carbonate, sufficient (with the fixed acids), to convert the whole of the bases into neutral salts. The nearest approach to this was in the case of plot 7 (Table II.), in which the produce contained the largest proportion of leguminous, and the least of gramineous herbage; whilst, where the produce was more prominently gramineous, and the ash the more silicious, the carbonic acid was much less completely restored.

APPENDIX TABLE II.—Results of actual analyses of the ashes of the Mixed Herbage of Grass-land, calculated into percentage, excluding sand, charcoal, and carbonic acid determined in the ash ignited at low red heat, but including carbonic acid determined after treatment of the ash with a solution of ammonium-carbonate and drying at 125°–130° C.

(Chiefly "Mixed-year" samples.)

	Group 3. Plots with Mineral Manures alone.														
	Mixed Mineral Manure, including Potash.					Sawdust alone (1856–1858).	Superphosphate of Lime alone, 1859 and since.		Mixed Mineral Manure, including Potash, 6 years, 1856–1861, excluding Potash 1862 and since. (Also sawdust first 7 years, 1856–62).				
	6 years 1856–1861.	1 year 1862.	3 years 1863–1865.	3 years 1866–1868.	5 years 1869–1873.	3 years 1856–1858.	7 years 1859–1865.	8 years 1866–1873.	6 years 1856–1861.	1 year 1862.	3 years 1863–1865.	3 years 1866–1868.	5 years 1869–1873.
	Plot 7.					Plot 4.	Plot 4–1.		Plot 8.				
Ferric oxide	0·32	0·77	0·63	0·44	0·36	0·40	0·45	0·69	0·35	0·75	0·46	0·36	0·43
Manganese oxide	0·56	0·36	0·79	0·75	0·85	0·52	0·58	0·60	0·46	0·63	0·70	0·75	0·78
Lime	12·71	11·03	12·40	10·78	11·54	15·26	15·39	16·95	12·78	11·40	12·61	12·76	12·34
Magnesia	3·39	3·41	3·70	3·43	3·53	4·26	4·51	4·61	3·22	3·71	3·97	4·13	4·52
Potash	31·15	35·15	32·56	37·46	38·16	20·73	17·92	18·55	30·66	29·53	24·17	23·32	21·67
Soda	2·91	1·15	1·34	0·83	0·48	6·98	7·86	7·52	3·12	3·29	5·81	6·86	8·75
Phosphoric acid	7·07	8·25	8·34	8·33	8·37	5·17	8·46	9·34	7·01	8·77	8·96	9·35	9·59
Sulphuric acid	7·63	6·56	7·67	5·89	5·72	6·97	8·34	7·52	7·36	7·07	10·21	7·87	7·34
Chlorine	5·84	5·09	6·05	5·07	5·28	6·02	5·75	5·77	5·83	5·39	5·12	5·21	5·80
Carbonic acid	12·61	10·80	12·36	13·68	13·91	11·82	10·45	9·01	13·06	8·74	7·96	10·18	9·49
Silica	17·13	18·58	15·53	14·48	12·99	23·23	21·58	20·74	17·46	21·93	21·18	20·39	20·59
Total	101·32	101·15	101·37	101·14	101·19	101·36	101·29	101·30	101·31	101·21	101·15	101·18	101·30
Deduct O = Cl.	1·32	1·15	1·37	1·14	1·19	1·36	1·29	1·30	1·31	1·21	1·15	1·18	1·30
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Determinations and estimates of Carbonic acid. Results culculated to 100 excluding Sand and Charcoal.

1. In ash ignited at low red heat	7·18	6·22	6·25	8·15	9·28	6·49	4·43	5·76	7·38	3·56	3·29	4·69	4·73
2. In ash after treatment with ammonium-carbonate and drying at 125–130° C.	12·61	10·80	12·36	13·68	13·91	11·82	10·45	9·01	13·06	8·74	7·96	10·18	9·49
3. Calculated requirement to form neutral salts, reckoning all phosphoric acid as tribasic	15·39	14·56	13·96	15·78	16·39	17·66	14·33	14·95	15·48	13·09	11·99	13·53	13·76

NOTE.—Examination of the figures relating to carbonic acid, given at the foot of the Appendix-Tables I., II., and III., will show that in none of these *mixed herbage ashes* was the amount found after treatment with a solution of ammonium-carbonate, sufficient (with the fixed acids), to convert the whole of the bases into neutral salts. The nearest approach to this was in the case of plot 7 (Table II.—above), in which the produce contained the largest proportion of leguminous, and the least of gramineous herbage; whilst, where the produce was more prominently gramineous, and the ash the more silicious, the carbonic acid was much less completely restored.

Appendix Table III.—Results of actual analyses of the ashes of the Mixed H
but including carbonic acid determine

	Mixed Min. Manure, and Amm.-salts = 86 lb. Nitrogen.		Mixed Mineral Manure, Ammonium-salts = 86 lb. Nitrogen, and Wheat Straw.					Mixed Min. Man., and Amm.-salts = 129 lb. Nitrogen 1856–61.	Mix. M Manur and Amm. = 172 lb. 1862 and	
	10 years 1856–1865.	8 years 1866–1873.	10 years 1856–1865.	1 year 1866.	7 years 1867–1873.	10 years 1856–1865.	8 years 1866–1873.	6 years 1856–1861.	4 years 1862–1865.	y 1 1
	Plot 9.		Plot 13–1.			Plot 13–2.		Plot 11.	Plot 11-	
Ferric oxide	0·48	0·43	0·43	0·63	0·44	0·48	0·44	0·66	0·66	
Manganese oxide	0·80	0·93	0·88	0·92	0·92	0·91	0·92	0·77	0·92	
Lime	8·74	7·69	8·32	6·82	6·62	8·57	6·61	9·43	7·05	
Magnesia	3·44	3·40	3·35	3·06	3·23	3·42	3·38	3·79	3·89	
Potash	32·85	39·01	35·53	39·86	39·84	34·52	37·69	29·63	35·81	3
Soda	5·10	2·34	3·94	0·83	2·48	4·46	3·88	6·85	4·83	
Phosphoric acid	7·44	8·60	7·88	8·25	8·32	7·48	7·88	6·84	7·91	
Sulphuric acid	6·32	5·05	6·11	5·00	4·93	6·31	5·06	5·96	5·48	
Chlorine	14·88	14·77	14·35	14·97	14·96	14·79	15·85	15·93	17·53	1
Carbonic acid	5·57	6·06	5·79	4·30	6·32	5·61	5·46	5·45	4·60	
Silica	17·74	15·05	16·66	18·74	15·31	16·78	16·41	18·28	15·28	1
Total	103·36	103·33	103·24	103·38	103·37	103·33	103·58	103·59	103·96	10
Deduct O = Cl.	3·36	3·33	3·24	3·38	3·37	3·33	3·58	3·59	3·96	
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	10

Determinations and

1. In ash ignited at low red heat	2·28	2·12	2·74	1·35	1·89	2·53	2·64	2·22	1·87	
2. In ash after treatment with ammonium-carbonate and drying at 125°–130° C.	5·57	6·06	5·79	4·30	6·32	5·61	5·46	5·45	4·60	
3. Calculated requirement to form neutral salts, reckoning all phosphoric acid as tribasic	9·55	9·35	9·60	7·89	9·09	9·72	8·96	10·20	8·36	

xed Herbage of Grass-land, calculated into percentage, excluding sand, charcoal, and carboni
ermined after treatment of the ash with a solution of ammonium-carbonate and drying at 1
(Chiefly "Mixed-year" Samples.)

Group 4.
Plots with Nitrogenous and Mineral Manures together.

Mix. Min. Manure, id Amm.-salts =172 lb. N. 362 and since.		Mix. Min. Man., Amm.-salts =172 lb. N. and silicates, 1862 and since.		Mix. Min. Man., and Nitrate Soda =86 lb. N., 1858 and since.		Mix. Min. Man., and Nitrate Soda =43 lb. N., 1858 and since.		Superphosphate, and Amm.-salts =86 lb. N., 1859 and since.		Mixed Mineral Manure, (including Potash 1856–1861, excluding Potash 1862 and sinc and Ammonium-salts =86 lb. Nitrogen. (Also sawdust first 7 years 1856–(				
4 ears 362– 865.	8 years 1866–1873.	4 years 1862–1865.	8 years 1866–1873.	8 years 1858–1865.	8 years 1866–1873.	8 years 1858–1865.	8 years 1866–1873.	7 years 1859–1865.	8 years 1866–1873.	6 years 1856–1861.	1 year 1862.	3 years 1863–1865.	3 years 1866–1868.	]
Plot 11–1.		Plot 11–2.		Plot 14.		Plot 16.		Plot 4–2.		Plot 10.				
0·66	0·35	0·72	0·40	0·68	0·99	0·55	0·52	0·74	0·82	0·44	0·84	0·69	0·48	
0·92	0·83	0·88	0·79	0·33	0·32	0·70	0·71	0·95	1·65	0·63	0·72	0·92	0·98	
7·05	5·38	6·79	5·48	8·85	7·69	9·72	8·22	15·25	14·22	9·21	8·24	9·76	10·38	
3·89	3·56	3·80	3·62	3·47	3·26	3·26	3·27	5·63	7·13	3·16	3·52	5·07	5·43	
5·81	37·16	34·48	36·44	26·97	30·00	30·39	34·65	16·73	14·98	29·51	25·97	18·07	15·72	
4·83	6·19	6·58	6·06	9·85	8·80	6·10	4·13	9·82	9·25	5·77	8·51	14·59	15·37	
7·91	7·87	7·72	7·84	6·88	7·81	7·39	8·52	9·87	13·08	6·83	9·09	9·42	9·98	
5·48	5·19	4·91	5·02	8·04	5·86	7·51	6·08	7·68	7·47	6·19	6·01	7·51	6·45	
7·53	17·96	18·42	18·47	6·92	5·69	6·36	5·78	12·02	9·46	14·95	11·39	13·80	13·32	
4·60	4·04	3·98	3·62	8·82	11·46	10·43	11·66	4·04	3·57	5·25	4·27	4·93	4·82	
5·28	15·52	15·87	16·43	20·75	19·40	18·29	17·77	19·99	20·50	21·43	24·01	18·35	20·08	
3·96	104·05	104·15	104·17	101·56	101·28	101·50	101·31	102·72	102·13	103·37	102·57	103·11	103·01	1
3·96	4·05	4·15	4·17	1·56	1·28	1·50	1·31	2·72	2·13	3·37	2·57	3·11	3·01	
0·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	1

is and estimates of Carbonic acid. Results calculated to 100 excluding Sand and Charcoal.

1·87	1·60	1·44	1·33	4·51	6·88	5·80	5·48	0·88	0·24	0·80	0·85	0·35	0·34
4·60	4·04	3·98	3·62	8·82	11·46	10·43	11·66	4·04	3·57	5·25	4·27	4·93	4·82
8·36	8·19	8·54	7·74	14·32	15·19	13·63	13·93	11·19	9·77	9·14	9·18	10·02	10·59

carbonic acid determined in the ash ignited at low red heat,
ıg at 125°–130° C.

...anure, ...56–1861, ... and since), ...-salts ...gen. ...rs 1856–62.)		Ammonium-salts = 86 lb. Nitrogen, 1856–1868; Mixed Mineral Manure, including Potash 1869 and since. (Also sawdust first 7 years 1856–62.)					
3 years 1866–1868.	5 years 1869–1873.	6 years 1856–1861.	1 year 1862.	3 years 1863–1865.	3 years 1866–1868.	5 years 1869–1873.	
		Plot 6.					
0·48	0·57	0·53	1·14	0·63	0·59	0·48	Ferric oxide
0·98	1·06	0·93	1·06	1·77	1·65	1·33	Manganese oxide
10·38	9·79	14·89	12·79	14·25	14·01	9·25	Lime
5·43	6·00	5·18	5·40	6·17	6·18	3·62	Magnesia
15·72	15·25	18·59	17·19	17·63	18·41	34·29	Potash
15·37	16·24	9·24	9·26	7·97	7·87	2·64	Soda
9·98	11·60	5·76	6·19	6·15	6·23	8·75	Phosphoric acid
6·45	6·65	7·72	6·81	8·48	7·90	7·09	Sulphuric acid
13·32	11·98	13·47	9·81	9·90	10·67	6·18	Chlorine
4·82	4·19	5·24	6·22	8·22	9·18	9·82	Carbonic acid
20·08	19·37	21·49	26·34	21·07	19·72	17·95	Silica
103·01	102·70	103·04	102·21	102·24	102·41	101·40	Total
3·01	2·70	3·04	2·21	2·24	2·41	1·40	Deduct O = Cl.
100·00	100·00	100·00	100·00	100·00	100·00	100·00	Total

0·34	0·71	1·47	2·24	1·47	2·15	4·12	1. In ash ignited at low red head
4·82	4·19	5·24	6·22	8·22	9·18	9·82	2. In ash after treatment with ammonium-carbonate and drying at 125°–130° C.
10·59	10·35	13·41	13·79	14·32	14·36	12·80	3. Calculated requirement to form neutral salts, reckoning all phosphoric acid as tribasic

tribasic										

NOTE.—Examination of the figures relating to carbonic acid, given at the foot of the Appendix Tabl
to convert the whole of the bases into neutral salts. The nearest approach to this was in the case of p
gramineous, and the ash the more silicious, the carbonic acid was much less completely restored.

dix Tables I., II., and III., will show that in none of these *mixed herbage ashes* was the amount found after treatment
ase of plot 7 (Table II.), in which the produce contained the largest proportion of leguminous, and the least of

							tribasic

reatment with a solution of ammonium-carbonate, sufficient (with the fixed acids), least of gramineous herbage; whilst, where the produce was more prominently

TABLE VII.—Percentage Composition of the Mixed Herbage of Grass-land (First Crops), grown by different Manures; including the Composition of the *Pure Ash*—Means of analyses of Mixed-year Samples. Total Period, 18 years, 1856–1873.

	Group 1. Plots without Manure, or with Farmyard Manure.							Group 2. Plots with Nitrogenous Manures alone.			Group 3. Plots with Mineral Manures alone.		
	Unmanured continuously.	Farmyard Manure 8 years 1856–63; Unmanured since.			Farmyard Manure and 43 lb. N. as Amm.-salts 8 years 1856–63; 43 lb. N. as Amm.-salts alone since.			Amm.-salts = 86 lb. Nitrogen.	Nitrate Soda = 86 lb. Nitrogen, 1858 and since.	Nitrate Soda = 43 lb. Nitrogen, 1858 and since.	Mixed Mineral Manure, including Potash.	Sawdust alone, 1856–1858.	Superphosphate of lime alone, 1859 and since.
		8 years 1856–1863.	10 years 1864–1873.	18 years 1856–1873.	8 years 1856–1863.	10 years 1864–1873.	18 years 1856–1873.						
	Plot 3.	Plot 2.			Plot 1.			Plot 5.	Plot 15.	Plot 17.	Plot 7.	Plot 4.	Plot 4–1.
NITROGEN and Mineral Matter—Percentage in the Dry Substance.													
Per cent. in Dry Matter: Nitrogen	1·66	1·46	1·31	1·38	1·50	1·44	1·46	2·16	1·89	1·74	1·74	1·77	1·58
Crude Ash	6·82	8·29	6·62	7·36	8·11	6·24	7·07	5·85	6·54	6·79	7·70	7·09	7·10
Pure Ash	7·03	8·42	6·79	7·52	8·20	6·34	7·17	6·02	6·84	7·02	8·02	7·40	7·23
COMPOSITION of the Pure Ash—per cent.													
Ferric oxide	0·58	0·47	0·46	0·47	0·56	0·54	0·55	0·57	0·60	0·78	0·43	0·40	0·58
Manganese oxide	0·54	0·22	0·34	0·29	0·31	0·65	0·50	1·42	0·33	0·59	0·70	0·52	0·59
Lime	17·26	10·52	12·11	11·40	11·34	12·64	12·06	14·03	10·48	12·03	11·92	15·26	16·22
Magnesia	4·58	3·18	4·21	3·75	3·30	4·88	4·18	6·17	4·22	4·23	3·49	4·26	4·56
Potash	19·10	30·74	24·31	27·16	29·68	21·39	25·07	17·74	14·53	16·93	34·60	20·73	18·26
Soda	6·88	2·82	5·03	4·05	3·97	8·42	6·45	8·48	18·02	13·14	1·53	6·98	7·68
Phosphoric acid	5·24	6·92	6·67	6·78	6·67	6·96	6·83	6·39	5·33	5·12	7·92	5·17	8·93
Sulphuric acid	5·98	4·76	4·69	4·72	4·99	5·81	5·44	8·25	5·52	5·73	6·76	6·97	7·90
Chlorine	5·97	8·98	5·14	6·85	12·94	11·85	12·33	11·15	6·45	6·53	5·55	6·02	5·76
Carbonic acid†	12·15	8·12	10·06	9·20	5·62	5·49	5·55	6·20	14·58	13·10	13·00	11·82	9·68
Silica	23·06	25·29	28·13	26·87	23·54	24·05	23·82	22·11	21·40	23·30	15·35	23·23	21·13
Total	101·34	102·02	101·15	101·54	102·92	102·68	102·78	102·51	101·46	101·48	101·25	101·36	101·29
Deduct O = Cl.	1·34	2·02	1·15	1·54	2·92	2·68	2·78	2·51	1·46	1·48	1·25	1·36	1·29
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

	Group 3 (cont.)		Group 4. Plots with Nitrogenous and Mineral Manures together.										Mixed Mineral Manure, after Ammonium-salts.	
	Mixed Mineral Manure including Potash, 1856–1861. *	Mixed Mineral Manure excluding Potash, 1862 and since. *	Mixed Mineral Manure, and Amm.-salts = 86 lb. Nitrogen.	Mixed Min. Man., and Amm.-salts = 86 lb. Nitrogen, and Wheat Straw.	Mixed Min. Man., and Amm.-salts = 129 lb. Nitrogen, 1856–1861.	Mixed Min. Man., and Amm.-salts = 172 lb. Nitrogen, 1862 and since.	Mixed Min. Man., and Amm.-salts = 172 lb. N., and silicates, 1862 and since.	Mixed Min. Man., and Nitrate Soda = 86 lb. Nitrogen, 1858 and since.	Mixed Min. Man., and Nitrate Soda = 43 lb. Nitrogen, 1858 and since.	Superphosphate, and Amm.-salts = 86 lb. Nitrogen, 1859 and since.	Mixed Min. including Potash, and Amm.-salts = 86 lb. N., 1856–1861. *	Mixed Man. excluding Potash, and Amm.-salts = 86 lb. N., 1862 and since. *	Amm.-salts = 86 lb. Nitrogen, 1856–1868. *	Mixed Mineral Manure including Potash, 1869 and since.
	Plot 8.		Plot 9.	Plot 13.	Plot 11.	Plot 11–1.	Plot 11–2.	Plot 14.	Plot 16.	Plot 4–2.	Plot 10.		Plot 6.	
NITROGEN and Mineral Matter—Percentage in the Dry Substance.														
Nitrogen (Per cent. in Dry Matter)	1·82	1·58	1·55	1·58	1·74	2·03	1·95	1·31	1·46	1·95	1·43	1·84	2·10	1·46
Crude Ash	8·07	7·00	7·11	7·37	7·72	6·98	7·12	6·89	7·29	6·17	8·19	6·25	6·10	6·32
Pure Ash	8·45	7·22	7·24	7·46	7·73	7·02	7·13	6·96	7·56	6·18	8·35	6·32	6·29	6·56
COMPOSITION of the Pure Ash—per cent.														
Ferric oxide	0·35	0·45	0·46	0·46	0·66	0·45	0·51	0·83	0·54	0·78	0·44	0·60	0·61	0·48
Manganese oxide	0·46	0·74	0·86	0·91	0·77	0·86	0·82	0·33	0·70	1·32	0·63	0·98	1·30	1·33
Lime	12·78	12·43	8·27	7·64	9·43	5·94	5·92	8·27	8·97	14·70	9·21	9·80	14·38	9·25
Magnesia	3·22	4·22	3·42	3·34	3·79	3·67	3·68	3·36	3·27	6·43	3·16	5·42	5·66	3·62
Potash	30·66	23·36	35·59	36·68	29·63	36·71	35·79	28·49	32·52	15·80	29·51	16·96	18·22	34·29
Soda	3·12	7·09	3·87	3·70	6·85	5·73	6·23	9·32	5·11	9·52	5·77	14·97	8·63	2·64
Phosphoric acid	7·01	9·30	7·96	7·86	6·84	7·88	7·80	7·34	8·21	11·58	6·83	10·44	5·99	8·75
Sulphuric acid	7·36	8·17	5·76	5·67	5·96	5·29	4·98	6·95	6·79	7·57	6·19	6·76	7·87	7·09
Chlorine	5·83	5·45	14·83	14·94	15·93	17·82	18·45	6·31	6·22	10·66	14·95	12·72	11·72	6·18
Carbonic acid†	13·06	9·22	5·79	5·73	5·45	4·23	3·74	10·14	11·05	3·79	5·25	4·54	6·91	9·82
Silica	17·46	20·80	16·54	16·44	18·28	15·44	16·24	20·08	18·03	20·26	21·43	19·68	21·36	17·95
Total	101·31	101·23	103·35	103·37	103·59	104·02	104·16	101·42	101·41	102·41	103·37	102·87	102·65	101·40
Deduct O = Cl.	1·31	1·23	3·35	3·37	3·59	4·02	4·16	1·42	1·41	2·41	3·37	2·87	2·65	1·40
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

* Also sawdust (but practically without effect) first 7 years, 1856–62.

† Second determination—after treatment with a solution of ammonium-carbonate.

Appendix Table III.—Results of actual analyses of the ashes of the Mixed Herbage of Grass-land, calculated into percentage, excluding sand, charcoal, and carbonic acid determined in the ash ignited at low red heat, but including carbonic acid determined after treatment of the ash with a solution of ammonium-carbonate and drying at 125°–130° C.
(Chiefly "Mixed-year" Samples.)

Group 4. Plots with Nitrogenous and Mineral Manures together.

	Mixed Min. Manure, and Amm.-salts = 86 lb. Nitrogen.		Mixed Mineral Manure, Ammonium-salts = 86 lb. Nitrogen, and Wheat Straw.					Mixed Min. Man., and Amm.-salts = 129 lb. Nitrogen 1856–61.	Mix. Min. Manure, and Amm.-salts = 172 lb. N. 1862 and since.		Mix. Min. Man., Amm.-salts = 172 lb. N. and silicates, 1862 and since.	
	10 years 1856–1865.	8 years 1866–1873.	10 years 1856–1865.	1 year 1866.	7 years 1867–1873.	10 years 1856–1865.	8 years 1866–1873.	6 years 1856–1861.	4 years 1862–1865.	8 years 1866–1873.	4 years 1862–1865.	8 years 1866–1873.
	Plot 9.		Plot 13–1.			Plot 13–2.		Plot 11.	Plot 11–1.		Plot 11–2.	
Ferric oxide	0·48	0·43	0·43	0·63	0·44	0·48	0·44	0·66	0·66	0·35	0·72	0·40
Manganese oxide	0·80	0·93	0·88	0·92	0·92	0·91	0·92	0·77	0·92	0·83	0·88	0·79
Lime	8·74	7·69	8·32	6·82	6·62	8·57	6·61	9·43	7·05	5·38	6·79	5·48
Magnesia	3·44	3·40	3·35	3·06	3·23	3·42	3·38	3·79	3·89	3·56	3·80	3·62
Potash	32·85	39·01	35·53	39·86	39·84	34·52	37·69	29·63	35·81	37·16	34·48	36·44
Soda	5·10	2·34	3·94	0·83	2·48	4·46	3·88	6·85	4·83	6·19	6·58	6·06
Phosphoric acid	7·44	8·60	7·88	8·25	8·32	7·48	7·88	6·84	7·91	7·87	7·72	7·84
Sulphuric acid	6·32	5·05	6·11	5·00	4·93	6·31	5·06	5·96	5·48	5·19	4·91	5·02
Chlorine	14·88	14·77	14·35	14·97	14·96	14·79	15·85	15·93	17·53	17·96	18·42	18·47
Carbonic acid	5·57	6·06	5·79	4·30	6·32	5·61	5·46	5·45	4·60	4·04	3·98	3·62
Silica	17·74	15·05	16·66	18·74	15·31	16·78	16·41	18·28	15·28	15·52	15·87	16·43
Total	103·36	103·33	103·24	103·38	103·37	103·33	103·58	103·59	103·96	104·05	104·15	104·17
Deduct O = Cl.	3·36	3·33	3·24	3·38	3·37	3·33	3·58	3·59	3·96	4·05	4·15	4·17
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

	Mix. Min. Man., and Nitrate Soda = 86 lb. N., 1858 and since.		Mix. Min. Man., and Nitrate Soda = 43 lb. N., 1858 and since.		Superphosphate, and Amm.-salts = 86 lb. N., 1859 and since.		Mixed Mineral Manure, (including Potash 1856–1861, excluding Potash 1862 and since), and Ammonium-salts = 86 lb. Nitrogen. (Also sawdust first 7 years 1856–62.)					Ammonium-salts = 86 lb. Nitrogen, 1856–1868; Mixed Mineral Manure, including Potash 1869 and since. (Also sawdust first 7 years 1856–62.)					
	8 years 1858–1865.	8 years 1866–1873.	8 years 1858–1865.	8 years 1866–1873.	7 years 1859–1865.	8 years 1866–1873.	6 years 1856–1861.	1 year 1862.	3 years 1863–1865.	3 years 1866–1868.	5 years 1869–1873.	6 years 1856–1861.	1 year 1862.	3 years 1863–1865.	3 years 1866–1868.	5 years 1869–1873.	
	Plot 14.		Plot 16.		Plot 4–2.		Plot 10.					Plot 6.					
Ferric oxide	0·68	0·99	0·55	0·52	0·74	0·82	0·44	0·84	0·69	0·48	0·57	0·53	1·14	0·63	0·59	0·48	Ferric oxide
Manganese oxide	0·33	0·32	0·70	0·71	0·95	1·65	0·63	0·72	0·92	0·98	1·06	0·93	1·06	1·77	1·65	1·33	Manganese oxide
Lime	8·85	7·69	9·72	8·22	15·25	14·22	9·21	8·24	9·76	10·38	9·79	14·89	12·79	14·25	14·01	9·25	Lime
Magnesia	3·47	3·26	3·26	3·27	5·63	7·13	3·16	3·52	5·07	5·43	6·00	5·18	5·40	6·17	6·18	3·62	Magnesia
Potash	26·97	30·00	30·39	34·65	16·73	14·98	29·51	25·97	18·07	15·72	15·25	18·59	17·19	17·63	18·41	34·29	Potash
Soda	9·85	8·80	6·10	4·13	9·82	9·25	5·77	8·51	14·59	15·37	16·24	9·24	9·26	7·97	7·87	2·64	Soda
Phosphoric acid	6·88	7·81	7·39	8·52	9·87	13·08	6·83	9·09	9·42	9·98	11·60	5·76	6·19	6·15	6·23	8·75	Phosphoric acid
Sulphuric acid	8·04	5·86	7·51	6·08	7·68	7·47	6·19	6·01	7·51	6·45	6·65	7·72	6·81	8·48	7·90	7·09	Sulphuric acid
Chlorine	6·92	5·69	6·36	5·78	12·02	9·46	14·95	11·39	13·80	13·32	11·98	13·47	9·81	9·90	10·67	6·18	Chlorine
Carbonic acid	8·82	11·46	10·43	11·66	4·04	3·57	5·25	4·27	4·93	4·82	4·19	5·24	6·22	8·22	9·18	9·82	Carbonic acid
Silica	20·75	19·40	18·29	17·77	19·99	20·50	21·43	24·01	18·35	20·08	19·37	21·49	26·34	21·07	19·72	17·95	Silica
Total	101·56	101·28	101·50	101·31	102·72	102·13	103·37	102·57	103·11	103·01	102·70	103·04	102·21	102·24	102·41	101·40	Total
Deduct O = Cl.	1·56	1·28	1·50	1·31	2·72	2·13	3·37	2·57	3·11	3·01	2·70	3·04	2·21	2·24	2·41	1·40	Deduct O = Cl.
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	Total

Determinations and estimates of Carbonic acid. Results calculated to 100 excluding Sand and Charcoal.

	Plot 9		Plot 13–1			Plot 13–2		Plot 11	Plot 11–1		Plot 11–2	
1. In ash ignited at low red heat	2·28	2·12	2·74	1·35	1·89	2·53	2·64	2·22	1·87	1·60	1·44	1·33
2. In ash after treatment with ammonium-carbonate and drying at 125°–130° C.	5·57	6·06	5·79	4·30	6·32	5·61	5·46	5·45	4·60	4·04	3·98	3·62
3. Calculated requirement to form neutral salts, reckoning all phosphoric acid as tribasic	9·55	9·35	9·60	7·89	9·09	9·72	8·96	10·20	8·36	8·19	8·54	7·74

	Plot 14		Plot 16		Plot 4–2		Plot 10					Plot 6					
1. In ash ignited at low red heat	4·51	6·88	5·80	5·48	0·88	0·24	0·80	0·85	0·35	0·34	0·71	1·47	2·24	1·47	2·15	4·12	1. In ash ignited at low red head
2. In ash after treatment with ammonium-carbonate and drying at 125°–130° C.	8·82	11·46	10·43	11·66	4·04	3·57	5·25	4·27	4·93	4·82	4·19	5·24	6·22	8·22	9·18	9·82	2. In ash after treatment with ammonium-carbonate and drying at 125°–130° C.
3. Calculated requirement to form neutral salts, reckoning all phosphoric acid as tribasic	14·32	15·19	13·63	13·93	11·19	9·77	9·14	9·18	10·02	10·59	10·35	13·41	13·79	14·32	14·36	12·80	3. Calculated requirement to form neutral salts, reckoning all phosphoric acid as tribasic

Note.—Examination of the figures relating to carbonic acid, given at the foot of the Appendix Tables I., II., and III., will show that in none of these *mixed herbage ashes* was the amount found after treatment with a solution of ammonium-carbonate, sufficient (with the fixed acids), to convert the whole of the bases into neutral salts. The nearest approach to this was in the case of plot 7 (Table II.), in which the produce contained the largest proportion of leguminous, and the least of gramineous herbage; whilst, where the produce was more prominently gramineous, and the ash the more silicious, the carbonic acid was much less completely restored.