ART. II.—*On Some Points in Connection with Vegetation:* by DR. J. H. GILBERT.*

THE subject of vegetation is such a very wide one, and might be treated of in so many different ways, that it seems desirable to state at the outset what is the scope, and what are the limits, of the discussion which I propose to bring before you. I propose, then, to confine attention almost exclusively to the question of the *Sources of the nitrogen of vegetation in general, and of agricultural production in particular.* I propose further to treat of this subject mainly in the aspects in which it has forced itself upon the attention of Mr. Lawes and myself during the now thirty-three years of our agricultural investigations; and, also, in so far as it illustrates, and is illustrated by, the objects contributed by Mr. Lawes to the Exhibition around us.

Before entering upon the special subject matter of my discourse, I must claim the indulgence of those present, who are already well acquainted with the main facts of the chemistry of vegetation, while I call attention, very briefly, to some rather elementary matters, with a view of rendering what has to follow the more intelligible to any who may be less fully informed on the subject.

When a vegetable substance is burnt—as a familiar instance, let us say tobacco, for example—the greater part of it is dissipated, but there remains a white ash. The ashes of crude or unripe vegetable substances are found on analysis to contain most, or all, of the following constituents, namely:—

Oxide of iron, oxide of manganese, lime, magnesia, potass, soda, phosphoric acid, sulphuric acid, chlorine, and silica.

Rarer substances than these are also sometimes found. Now, much has of late years been established in regard to the occurrence, and the offices, of some of these substances in plants; but I do not propose to touch upon the questions herein involved. It will suffice further to say in regard to these incombustible, or "mineral" constituents, that the ash of one and the same description of plant, growing on different soils, may, so long as it is in the growing or immature state, differ very much in composition. Again, the ashes of different species, growing on the same soil, will differ very widely in the proportion of their several constituents. But it is found that the nearer we approach to the elaboration of the final products of the plant—the seed, for example—the more fixed is the composition of ash of such products of one and the same species. In other

* An address delivered at South Kensington, in the Chemical Section of the Science Conferences, by Dr. J. H. Gilbert, F.R.S., F.L.S., F.C.S.

words, there is very little variation in the composition of the ash of one and the same description of seed, or other final product, provided it be evenly and perfectly matured. This fact alone, independently of all that has been established of late years in regard to the office or function, so to speak, of individual mineral constituents of plants, would be sufficient to indicate the essentialness of such constituents for healthy growth; and it is obvious that they must be provided *within the soil.*

But now as to the combustible constituents—the carbon, the hydrogen, the oxygen, and the nitrogen. Leaving out of consideration such exceptional cases as those brought to light in Mr. Darwin's beautiful investigation on insectivorous plants, and also the sources of the organic substance of fungi, and perhaps of some forced horticultural productions, it may be stated, that the source of the carbon of vegetation generally is the carbonic acid existing in very small proportion, but in large actual amount, in the atmosphere; that the source of the hydrogen is water; and that the source of the oxygen may be either that in carbonic acid, or that in water. With regard to the nitrogen the case is, however, by no means so simple. Not that there are no questions still open for investigation in regard to the assimilation by plants of their incombustible or mineral constituents, or of their carbon, their hydrogen, and their oxygen; but those relating to the sources, and to the assimilation, of their nitrogon, are not only in many respects of more importance, but seem to involve greater difficulties in their solution.

What, then, are the sources of the nitrogen of vegetation? Are they the same for all descriptions of plants? Are they to be sought entirely in the soil? or entirely in the atmosphere? or partly in the one, and partly in the other?

Amount of nitrogen carried down by atmospheric precipitation.—As the combined nitrogen coming down from the atmosphere in rain, hail, snow, mists, fog, and dew, does undoubtedly contribute to the annual yield of nitrogen in our crops, let us first briefly consider what is known as to the amount of it annually so coming down over a given area of the earth's surface; and as we are here discussing the subject in England, I will adopt the English pound as the unit of weight, and the English acre as the unit of area. The following table shows the amount of nitrogen coming down as ammonia and nitric acid in the total rain, hail, snow, and some of the minor deposits, during the years 1853, 1855, and 1856, at Rothamsted (Herts), the nitric acid being, in all cases determined by Mr. Way, and the ammonia in some cases by him, and in others by ourselves:—

TABLE I.—*Combined Nitrogen in Rain and Minor Aqueous Deposits at Rothamsted.*

	Nitrogen per acre, per annum, lbs.			
	1853.	1855.	1856.	Mean.
As ammonia	5·67	5·86	7·85	6·46
As nitric acid	(not determined)	0·77	0·73	0·75
Total		6·63	8·58	7·21

Numerous determinations of the ammonia and nitric acid in rain, and the other aqueous deposits, have been made in various parts of France and Germany, some in the vicinity of towns, and some in the open country. Of the latter, which are the most to our purpose, it may be stated that those of Boussingault at Liebfrauenberg, in Alsace, generally indicate a larger proportion of the nitrogen existing as nitric acid, and less as ammonia than our own; but, upon the whole, the observations in the two widely separated localities mutually confirm one another. Of the results of others, in other localities, some show about the same amount of combined nitrogen so deposited as our own, some, however, much more, and some much less, than ours; but the determinations on the Continent generally show a higher proportion of the total combined nitrogen to exist as nitrates than those in this country. It may be added, that numerous determinations of the combined nitrogen in rain, dew, etc., collected at Rothamsted, have much more recently been made by Professor Frankland, and his results, which are published in the "Sixth Report of the Rivers Pollution Commission," are substantially confirmatory of the earlier determinations, summarized in the foregoing Table, but upon the whole they indicate lower amounts. Lastly, M. Marié-Davy determined the ammonia in the rain, etc., collected at the Meteorological Observatory at Montsouris, Paris, during the last six months of 1875; and the amount of ammonia so coming down, even within the walls of Paris, represented only 5·25 lbs. of combined nitrogen per acre, or only 10·5 lbs. per acre, per annum. M. Marié-Davy did not make a complete series of determinations of the nitric acid in the meteoric waters, but his initiative results agree with the experiments of others in showing the amount of combined nitrogen to be comparatively small.

Thus, the determinations hitherto made of the amount of combined nitrogen coming down in the measured aqueous deposits from the atmosphere, do not justify us in assuming that the quantity available from that source will exceed eight or ten lbs. per acre, per annum, in the open country, in Western Europe. It should be observed, however, that the amount of ammonia especially is very much greater in a given volume of the minor aqueous deposits than it is in rain; and there can be little doubt that there would be more ammonia deposited from them within the pores of a given area of soil, than on an equal area of the non-porous even surface of a rain gauge. How much, however, would thus be available to the vegetation of a given area beyond that determined in the collected and measured aqueous deposits, we have not the means of estimating with any certainty. On the other hand, numerous independent determinations, by both Dr. Voelcker and Dr. Frankland, of the nitric acid in the drainage-water collected from land at Rothamsted which had been many years unmanured, lead to the conclusion that there may be a considerable annual loss of nitrogen by the soil in that way.

Amount of nitrogen derived by crops of different kinds when grown without manure.—The next point to consider is, what is the amount of nitrogen annually obtained over a given area, in different crops, when they are grown without any supply of it in manure. This point may be illustrated by the results obtained in the field experiments on Mr. Lawes' farm at Rothamsted, which have now been in progress for about a third

TABLE II.—*Yield of Nitrogen per acre, per annum, in Wheat, Barley, and Root Crops, at Rothamsted.*

Crop. &c.	Condition of Manuring, &c.		Duration of Experiment.	Average Nitrogen per acre, per annum.
				lbs.
Wheat.	Unmanured		8 yrs. 1844-'51	25·2
			12 yrs. 1852-'63	22·6
			12 yrs. 1864-'75	15·9
			24 yrs. 1852-'75	19·3
			32 yrs. 1844-'75	20·7
	Complex Mineral Manure		12 yrs. 1852-'63	27·0
			12 yrs. 1864-'75	17·2
			24 yrs. 1852-'75	22·1
Barley.	Unmanured		12 yrs. 1852-'63	22·0
			12 yrs. 1864-'75	14·6
			24 yrs. 1852-'75	18·3
	Complex Mineral Manure		12 yrs. 1852-'63	26·0
			12 yrs. 1864-'75	18·8
			24 yrs. 1852-'75	22·4
Root Crops.	Complex Mineral Manure.	Turnips	8 yrs. 1845-'52	42·0
		Barley	3 yrs. 1853-'55	24·3
		Turnips	15 yrs. 1856-'70*	18·5
		Sugar-beet	5 yrs. 1871-'75	13·1
		Total	31 yrs. 1845-'75	26·8

* Thirteen years' crop—two years failed.

of a century. Table II shows the yield of nitrogen per acre, per annum, in wheat, in barley, and in root crops, each grown for many years in succession on the same land, either without any manure, or with only a complex mineral manure, that is supplying no nitrogen.

Bearing in mind what has been said as to the amount of combined nitrogen known to be annually deposited from the atmosphere, the figures in Table II have great interest and significance. Thus, over a period of thirty-two years, the wheat has yielded an average of 20·7 lbs. of nitrogen, per acre, per annum, without manure. But if we look at the quantities yielded during the first eight, the next twelve, and the last twelve years of that period, it is seen that there has been a gradual, but at the same time a considerable decline in the annual yield. From this it would appear probable that the nitrogen of the soil derived from previous accumulations, is being gradually reduced. Whether or not the whole of the excess of yield over that available from the rain, and other measured aqueous deposits from the atmosphere, is due to previous accumulations within the soil, and is therefore inducing a gradual exhaustion of its stock of nitrogen to that extent, we have not conclusive evidence to show. Determinations of nitrogen in samples of the soil taken at different times during the course of the experiments do, indeed, show an appreciable reduction. It is probable, however, that a part of the excess of yield is due to condensation of ammonia within the pores of the soil, beyond that which would be deposited in rain, and in the dew and other minor deposits condensed on the non-porous even surface of a rain-gauge, as already referred to.

Excluding the first eight years of the growth of wheat, it is seen that while over the next twenty-four years, 1852–1875, the wheat yielded 19·3 lbs. of nitrogen, per acre, per annum; the barley yielded an average of 18·3 lbs. over the same period. Again, during the first twelve of the twenty-four years, the wheat yielded 22·6 lbs., and the barley 22 lbs.; while, during the second twelve years, the yield in wheat was reduced to 15·9, and that in the barley to 14·6 lbs. The similarity in the yield of nitrogen over the same periods in these two closely allied crops, growing in different fields, is very striking, though, upon the whole, the indication is that the autumn-sown wheat has accumulated more than the spring-sown barley.

It is next to be observed that the annual use of a complex mineral manure has but very slightly increased the yield of nitrogen in either of these gramineous crops; and it is probable that the increased yield, such as it is, is derived from the previous accumulations within the soil, and not from atmospheric sources.

To sum up the evidence in regard to the sources of the nitrogen of these two typical gramineous plants, when none of it is supplied to them by manure, though it is not conclusively shown whence the whole of it is derived, it would at any rate appear probable, that it may be accounted for by the combined nitrogen coming down in rain and in the other measured aqueous deposits from the atmosphere, by the condensation of the ammonia of the air within the pores of the soil, and by the previous accumulations within the soil.

Let us now consider what is the yield of nitrogen by plants of other natural families, and first of all by certain so-called "root-crops"—turnips of the natural order Cruciferæ, and sugar beet of the order Chenopodiaceæ. On this point we have the experience of thirty-one years, excepting that during three of those years barley was grown without any manure in order to equalise the condition of the land as far as possible before re-arranging the manuring, and during two other years the turnips failed and there was no crop.

It should be premised that when root-crops are grown without manure of any kind, there is after a few years scarcely any produce at all; and hence the results recorded in the table are those obtained by the use of mineral manures, but without any supply of nitrogen. It is seen that during the first eight years of turnips, there was an average yield of 42 lbs. of nitrogen per acre, per annum. During the next three years barley yielded 24·3 lbs. annually. During the next fifteen years, thirteen with Swedish turnips, and two without any crop, there was a yield of 18·5 lbs. per acre annually. During the last five years sugar-beet yielded 13·1 lbs. per acre, per annum Lastly, over the whole thirty-one years, during which there were three crops of barley, two years without any crop, twenty-one years of turnips, and five of sugar-beet, the average annual yield was 26·8 lbs. of nitrogen.

Here, then, we have a reduction to less than one-third during the later compared with the earlier years, and to a lower point than even with either wheat or barley: though, during the whole period, the annual yield is higher than with either of the two gramineous crops. It may be mentioned that we have other experimental evidence showing that the so-called "root-crops" exhaust at any rate the superficial layers of the soil of their available supplies of nitrogen, more completely than perhaps any other crop. It may further be added that the surface soil has shown during recent years a lower percentage of nitrogen than that of any of the other experimental fields. We have fair grounds for concluding, therefore, that if in the cases of the wheat and the barley the nitrogen yielded beyond that retained by the soil from the direct measurable aqueous deposits, together with that condensed within the pores of the soil from the atmosphere, be derived from previous accumulations within the soil, so also may the excess of yield by the so-called "root-crops" be accounted for.

We now come to the consideration of the yield of nitrogen when plants of the *leguminous* family are separately grown, or when they, and plants of some other families, are grown in alternation, or in association, with the Gramineæ. Table III shows the results obtained with beans, and with clover; with clover and barley grown in alternation; and with turnips, barley, clover or beans, and wheat, grown in an actual course of rotation.

TABLE III.—*Yield of Nitrogen per acre, per annum in Beans, in Red Clover, and in Rotation.*

Crops, &c.	Conditions of Manuring, &c.	Duration of Experiment.	Average Nitrogen per acre, per annum.
			lbs.
Beans	Unmanured	12 yrs. 1847-'58	48·1
		12 yrs. 1859-'70(*)	14·6
		24 yrs. 1847-'70	31·3
	Complex Mineral Manure	12 yrs. 1847-'58	61·5
		12 yrs. 1859-'70(*)	29·5
		24 yrs. 1847-'70	45·5
Clover	Unmanured	22 yrs. 1849-'70(†)	30·5
	Complex Mineral Manure	22 yrs. 1849-'70(†)	39·8
Barley	Unmanured	1 yr. 1873	37·3
Clover		1 yr. 1873	151·3
Barley	Unmanured — After Barley	1 yr. 1874	39·1
	Unmanured — After Clover	1 yr. 1874	69·4
	Barley after Clover more than after Barley		30·3
Rotation 7 Courses	1 Turnips, 2 Barley, 3 Clover or Beans, 4 Wheat — Unmanured	28 yrs. 1848-'75	36·8
	1 Turnips, 2 Barley, 3 Clover or Beans, 4 Wheat — Superphosphate	28 yrs. 1847-'75	45·2

Referring first to the results obtained with beans the table shows that without manure there was an annual yield over the first twelve years, 1847–1858, of 48·1 lbs. of nitrogen. Over the next twelve years, 1859–1870, it was reduced to 14·6 lbs. per acre, per annum. Still, over the whole period of twenty-four years, we have an annual yield of 31·3 lbs., or more than one and a half time as much as in either wheat or barley.

(*) Nine years Beans, one year Wheat, two years fallow.
(†) Six years Clover, one year Wheat, three years Barley, twelve years fallow.

In the case of wheat and barley it was seen that a mixed mineral manure increased the yield of nitrogen to a very small degree only. Not so in the case of the leguminous crop, beans. During the first twelve years a complex mineral manure, containing a large amount of potass—I call attention to this fact because we have abundant evidence that it is the potass chiefly that is effective—gave 61·5 lbs. of nitrogen per acre per annum against 48·1 lbs. obtained over the same period without manure. During the next twelve years, the potass manure gave 29·5 lbs. against scarcely half as much, or 14·6 lbs. without the potass manure. And finally, during the whole period of twenty-four years, the potass manure has given 45·5 lbs. of nitrogen per acre, per annum, against 31·3 lbs., or only about two thirds as much, without manure; and we have more than twice as much yielded by a potass manure over a period of twenty four years with beans than with either wheat or barley.

Before calling attention to the figures relating to another leguminous crop—red clover—it should be mentioned that leguminous crops generally are, and clover in particular is, extremely sensitive to adverse climatal circumstances; but clover is pre eminently sensitive to soil conditions also. Indeed, it is a fact well recognized in agriculture, that few soils can be relied upon to grow a good crop of clover oftener than once in about eight years; and many soils will not yield it so frequently. It will not excite surprise, therefore, that in attempting to grow clover year after year on the same land, we have only succeeded in getting any crops, and some of those poor ones, in six years over a period of twenty-two. Indeed, the plant failed seven times out of eight during the winter and spring succeeding the sowing of the seed; when, in some cases a crop of wheat or barley was taken, and in others the land was left fallow. Hence, over a period of twenty-two years we have had only six years of clover, one of wheat, three of barley, and twelve of fallow. Still, the annual yield of nitrogen over the twenty-two years was 30·5 lbs. without any manure, and 39·8 lbs., or nearly one third more, by mineral manure containing potass. Unfavorable as was this experiment in an agricultural point of view, still it is seen that the influence of the interpolation of this leguminous crop has greatly increased the yield of nitrogen compared with that obtained in either wheat or barley grown continuously; and that, unlike the result with those crops, a potass manure has here again, as with beans, greatly increased the yield.

Without attempting for the moment to discuss the probable source or sources of this greatly increased yield of nitrogen by leguminous as compared with gramineous crops, I will simply here remark in passing that we have no evidence leading to the conclusion that this increased assimilation is at the expense of the nitrogen existing at any rate in the upper layers of the soil. In fact, such initiative results as we have relating to the nitrogen in the soil of the experimental bean field, would rather lead to the conclusion that the better the crop has grown, and the more nitrogen it has assimilated, the richer rather than the poorer in nitrogen (as indicated by the soda-lime method) has the surface soil become. To this point, however, we shall have to recur presently; but in the meantime let us first refer to the yield of nitrogen in other cases in which leguminous crops have been interpolated with others.

It is, indeed, well known that the growth and removal of a highly nitrogenous leguminous crop is one of the best possible preparations for the growth of a gramineous corn crop, which characteristically requires nitrogenous manuring. A striking illustration of this apparent anomaly is afforded in the results next in order recorded in Table III.

After the growth of six corn crops in succession by artificial manures alone, barley was grown without manure in 1873 on one portion of the same land; and on another portion clover was grown. It is calculated that there were taken off in the barley 37·3 lbs. of nitrogen, and in the three cuttings of clover 151·3 lbs. Yet, in the next year, 1874, barley succeeding the barley gave 39·1 lbs., and barley succeeding the clover gave 69·4 lbs. of nitrogen; or 30·3 lbs. more after the removal of 151·3 lbs. in clover than after the removal of 37·3 lbs. in barley. Nor was this remarkable result to be explained by either accident or error. For, determinations of nitrogen in four separately taken samples of the soil, in the mixture of the four, and in the mixture of six others, taken from each plot, and at different depths, all concurred in showing an appreciably higher percentage of nitrogen, especially in the surface soil, nine inches deep, of the land from which the clover had been removed than in that from which the barley had been taken; and this was so, although, in every case, all visible vegetable debris had been carefully picked out. Here, then, the surface soil at any rate was positively enriched in nitrogen (determinable by soda lime) by the growth and removal of a very highly nitrogenous crop. It may be mentioned that Dr. Voelcker has obtained results of a similar character.

The results next to be considered are those obtained in an actual four-course rotation of crops—namely, turnips, barley, clover or beans, and wheat. The experiments have been conducted through seven such courses; that is to say, over a period of twenty-eight years. One portion of the land, the results relating to which are given in the table, has been entirely unmanured during the whole of that period, and the other has received super-phosphate of lime alone, once every four years—that is to say, for the turnips commencing each course; but it has received no other manure throughout the twenty-eight years, either mineral or nitrogenous.

Under these conditions—that is with a turnip crop and a leguminous crop interpolated with two gramineous crops—we have, without manure of any kind, an average of 36·8 lbs. of nitrogen yielded per acre, per annum; or not far from twice as much as was obtained with either of those cereal crops, wheat or barley, grown consecutively. With super-phosphate of lime alone, which, in a striking degree increased the yield of nitrogen in the turnips, reduced it in the succeeding barley, increased it greatly in the leguminous crops, and slightly in the wheat immediately following them, we have the average annual yield of nitrogen raised to 45·2 lbs. per acre, per annum, over the twenty-eight years; or to more than double that obtained by wheat or barley grown continuously by mineral manures alone. And it may be observed that where, in adjoining experiments, no leguminous crop was grown between the barley and the wheat, but the land was fallowed instead, the total yield of nitrogen in the rotation was very much less: the wheat succeeding the fallow yielding very little more nitogen than that succeeding the leguminous crops which had removed so much of it. In other words, the removal of the most highly nitrogenous crops of the rotation—beans or clover—has been succeeded by a growth of wheat, and assimilation of nitrogen by it, almost as great as when it has succeeded a year of fallow—that is to say, a period of accumulation from external sources, and no removal by crops.

One other illustration must be given of the power of plants of the leguminous and some other families to assimilate more nitrogen over a given area than those of the gramineous family. But before entering upon the bearing of the results in question on this particular point, it will be necessary to digress a little to call special attention to the conditions of the experiments under which the results were obtained: and it is the more desirable to do this, since the most important of Mr. Lawes' contributions to this Exhibition is an illustration of the results I am about to refer to.

Effects of manure.—I must here forestall a little what I shall have to refer to more fully further on, as to the effects of characteristically different substances on crops belonging to different botanical families. I will say briefly, then, that it is found that nitrogenous manures have generally a very striking effect in increasing the growth of gramineous crops grown separately on arable land, such as wheat, barley, or oats, all of which contain a comparatively small percentage of nitrogen, and, as has been illustrated, assimilate a comparatively small amount of it over a given area when none is supplied to them in manure. The highly nitrogenous leguminous crops, on the other hand, such as peas, beans, clover, and others, are by no means characteristically benefitted by the use of direct nitrogenous manures, such as ammonia-salts or nitrates, though nitrates act much more favorably than ammonia-salts. Again, while, under equal conditions of soil and seasons, mineral without nitrogenous manures increase comparatively little the poor-in-nitrogen gramineous crops that are grown separately, such manures, and especially potass-manures, as has been seen, increase in a striking degree, the growth of crops of the leguminous family grown separately, and coincidently the amount of nitrogen they assimilate over a given area.

Such, then, is the result obtained in the separate growth, on arable land, of individual plants of the different families. Now, in the mixed herbage of permanent grass land, we may have fifty, or even many more species growing together, representing nearly as many genera, and perhaps eighteen or twenty natural orders or families. Of these, the Gramineæ generally contribute the largest portion of the herbage; and, on good grass land, if the Leguminosæ do not come second, they are at any rate prominent. The degree in which other orders are represented may be very various indeed, according to soil, locality, season, and other circumstances. In Mr. Lawes' park, at Rothamsted, nearly eighty species have been observed; but of many only isolated specimens, and it may be stated generally that about fifty species are so prominent as to be found in a carefully averaged sample of the hay grown without manure.

Experiments on the influence of different manures on this mixed herbage were commenced in 1856; at which time the herbage was apparently pretty uniform over the whole area selected. About twenty plots, from one-quarter to one-half an acre each, were marked out, of which two have been left continuously without manure, and each of the others has received its own special manure, and as a rule the same description year after year—and the experiments have now been conducted over a period of twenty years.

Under this varied treatment, changes in the flora, so to speak, became apparent even in the first years of the experiments; and three times since their commencement, at intervals of five years—namely, in 1862, 1867, and 1872—a carefully averaged sample of the produce of each plot has been taken and submitted to careful botanical separation, and the percentage, *by weight*, of each species in the mixed herbage determined. Partial separations have also been made in other years.

Mr. Lawes has contributed a large case of specimens to the exhibition, which shows the botanical composition of the herbage on selected plots in the seventeenth season of the experiments (1872). The quantities of the different plants there exhibited represent the relative proportion, by weight, in which each species was found in the mixed produce of the different plots; and the whole illustrates in a striking manner the domination of one plant over another, under the influence of different manures, applied year after year on the same plot.

The general results of the experiments may be briefly summarized as follows:—

The mean produce of hay per acre per annum has ranged, on the different plots, from about twenty-three cwt. without manure to about sixty-four cwt. on the plot the most heavily manured.

The number of species found has generally been about fifty on the unmanured plots, and has been reduced to an average of only twenty, and has sometimes been less, on the most heavily manured plots.

Species belonging to the order *Gramineæ* have, on the average, contributed about sixty-eight per cent of the weight of the mixed herbage grown without manure; about sixty-five per cent of that grown by purely mineral manures (that is, without nitrogen); and about ninety-four per cent of that grown by the same mineral manures, with a large quantity of ammonia-salts in addition.

Species of the order *Leguminosæ* have, on the average, contributed about nine per cent of the produce without manure, about twenty per cent of that by purely mineral manures (containing potass), and less than 0·01 per cent of that by the mixture of the same mineral manures and a large quantity of ammoniacal salts.

Species belonging to various other orders have, on the average, contributed about twenty-three per cent of the produce without manure; about fifteen per cent of that by purely mineral manures, and only about six per cent of that by the mixture of the mineral manures and a large amount of ammonia-salts.

Not only the amounts of produce, but the number and description of the species developed, have varied very greatly between the extremes here quoted, according to the particular character or combination of manure employed, and to the character of the seasons, as is strikingly illustrated by the arrangement of the specimens in the case, which, however, it should be borne in mind, show the composition of the herbage on the selected plots in one particular season only—namely, in 1872.

Obviously, these few remarks can only very inadequately indicate the interest of these curious illustrations of the domination of one plant over another in the mixed herbage of permanent grass land. Nor do we pretend to be able to give a satisfactory explanation of the variations induced, founded on the obvious or recorded difference in above-ground or underground character or habit of growth of the individual species. The whole of the results—agricultural, chemical, and botanical—obtained during the twenty years of the experiments are, however, now in course of arrangement for publication; and that we may not overlook such explanations as might be suggested from the point of view of the botanist and vegetable physiologist, as well as that of the chemist, we have associated with ourselves Dr. Masters in working up the botanical part of the inquiry; and I think Dr. Masters will agree with me in saying that much more has yet to be known of the difference in the physiological capability, so to speak, of the leaves of plants of different species, genera, and orders, and of the difference in the distribution, and in the feeding power, of the roots, before satisfactory explanations of the facts observed can be given. Surely, a wide field of investigation for the botanist and vegetable physiologist is here opened up to view!

(To be continued.)

ART. III.—*Observations on a property of the Retina, first noticed by Tait;* by OGDEN N. ROOD, Professor of Physics in Columbia College.

IN the Edinburgh Proceedings, 1869–70, vii, p. 605–607, Tait described an interesting observation, which has perhaps some bearing on Thomas Young's theory of color. While suffering from indisposition, he noticed each time on awakening from a feverish sleep, that the flame of a lamp seen through a ground-glass shade, assumed a deep red color, the effect lasting about a second. He suggests that the nerve fibrils in the retina also partook of sleep, and on awakening the green and violet nerves resumed their function somewhat later than the red. I have in my own case noticed some instances, which seem to point out that after a *nervous shock*, sudden or prolonged, the green nerves (adopting the theory of Young,) recover their activity later than the red, and probably later than the violet nerves. The first observation was made twenty years ago while recovering from the effects of chloroform, which had been administered by a dentist, well known at that time in Munich. Upon regaining consciousness, and raising my eyes to the face of the operator, I was a little surprised at not having previously remarked his unusually ruddy complexion, but the next instant

ART. XI.—*On some Points in connection with Vegetation;* by Dr. J. H. GILBERT.

[Continued from page 32.]

Amount of nitrogen assimilated by plants.—Let us now recur to the question of the various amounts of nitrogen assimilated over a given area by plants of different natural orders, and call attention to the facts bearing upon the point which these experiments on the mixed herbage of grass land have supplied.

TABLE IV.—*Yield of Nitrogen in the Mixed Herbage of Permanent Grass land at Rothamsted.*

Plots.	Conditions of Manuring.	Average Produce per acre per annum, 20 years, 1856–1875, according to Mean per cent at 6 periods 1862, '67, '71, '72, '74, '75.			Average nitrogen per Acre per annum.		
		Gramineæ.	Leguminosæ.	Other Orders.	10 years 1856–1865	10 years 1866–1875	20 years 1856–1875
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
3	Unmanured	1635	219	529	35·1	30·9	33·0
4-1	Superphosphate*	1671	149	673	35·7	31·5	33·6
8	Complex Min. Manure.†	2442	296	639	54·4	38·1	46·3
7	Complex Min. Manure.‡	2579	806	573	55·2	56·0	55·6

In Table IV. is shown the average produce (in the condition of hay) in lbs., per acre, per annum, over twenty years, of herbage of the gramineous family, of herbage of the leguminous family, and of herbage of other orders, calculated according to the mean percentage of each of these, determined in separations at six periods, namely, in 1862, 1867, 1871, 1872, 1874, and 1875, in samples of the produce of four of the plots which have received no nitrogenous manure from the commencement; and there is also given, by the side of these results, the average annual yield of nitrogen per acre over the first ten, the second ten, and the total period of twenty years, in each case.

The quantities of nitrogen yielded are calculated from the results of actual determinations of the nitrogen in the mixed produce of the respective plots; but the estimates of the quantity of the produce referable to the different Natural Orders must be taken as only giving a general indication or an approximation to the truth; for, while the amount of the total mixed produce is the average of that of the twenty years,

* Mean of four separations only, namely, 1862, 1867, 1872 and 1875.

† Including potass six years, 1856–1861; without potass, fourteen years, 1862–1875.

‡ Including potass twenty years, 1856–1875.

the amount of it referred to the different orders is calculated upon their percentage determined in six years only, four of which are among the last five, and the fluctuation according to season is in some cases very considerable, while in others there is a progression in the changes, which render an accurate estimate of the average botanical composition of the herbage over the whole period impossible. The figures do, however, undoubtedly represent the truth sufficiently nearly for our present purpose. But before referring to the yield of nitrogen, it may be remarked, in passing, how much greater is the increase of gramineous produce by the use of purely mineral manures in this mixed herbage than in the case of gramineous crops grown separately. The interesting question arises, how far the result is due to the direct action of the mineral manures in enabling the grasses to form much more stem and seed—that is, the better to manure—which, as a matter of fact, they are found to do? or how far the increased growth is to be explained by an increased accumulation of combined nitrogen available for the grasses in the upper layers of the soil, as the result of the increased growth of the Leguminosæ induced by the potass-manure, as already illustrated by the results obtained in alternating clover and barley, and in an actual course of rotation?

Referring to the yield of nitrogen, it is seen that, without manure, it has diminished during the last as compared with the first ten years; but that the average is thirty-three pounds per acre, per annum, or considerably more than with a gramineous crop grown separately.

With super-phosphate of lime alone, the yield of nitrogen over the first ten, the second ten, and the twenty years, is very nearly the same as without manure. It is slightly higher as is also the total amount of produce; but while the quantity contributed by gramineous species is rather more, that yielded by leguminous species is less, and that by species belonging to other orders more than without manure.

With super-phosphate of lime, and sulphates of potass, soda and magnesia, during the first six years, but no potass during the last fourteen years (plot 8), the amount of both gramineous and leguminous herbage is very much increased; and that of the leguminous produce was especially so during the earlier years. The result is a yield of 55·4 lbs. of nitrogen per acre, per annum, over the first ten years, of only 38·1 lbs. over the second ten years, and of 46·3 lbs. over the twenty years.

With the complex mineral manure, including potass each year throughout the period of twenty years (plot 7), leguminous species contribute about one-fifth of the whole produce, or very much more than in either of the other cases. The result is an annual yield of 55·2 lbs. of nitrogen over the first ten years; of even slightly more, or fifty-six lbs., over the second ten years: and of 55·6 lbs. over the whole period of twenty years—that is, considerably more than twice as much as would be yielded by a gramineous crop grown separately on arable land. It may here be observed that, while in the case of the first three plots referred to, the produce of the mixed herbage diminished over the second as compared with the first ten years, that of plot 7, with the potass manure, and so much leguminous herbage, increased slightly over the second compared with the first ten years. Finally, it may be remarked on this point, how comparatively uniform is the average yield of produce by all other species other than the gramineous and the leguminous on the four very differently manured plots.

Here again, then, the results relating to the growth of species of many different natural orders growing together, like those relating to the growth of individual species grown separately, show that those of the leguminous family, and probably those of various other orders also, have the capacity of assimilating much more nitrogen over a given area than species of the order Gramineæ.

Assuming for the sake of argument that the yield of nitrogen by the Gramineæ grown separately may be explained, as already suggested, by reference to the amount of combined nitrogen acquired from the measured aqueous deposits from the atmosphere, together with that condensed within the pores of the soil, and that derived from previous accumulations within it, the question arises, can the greatly increased yield by other plants be so accounted for? or, if not, how otherwise may it be explained? We will endeavor to weigh the evidence bearing upon this point.

Is the combined nitrogen in the atmosphere the source of the assimilated nitrogen?—It so happens that the plants which do gather, or which have been supposed to gather nitrogen more readily than the Gramineæ, have obviously a different character of foliage; as, for instance, the "root crops"—turnips and the like; and the leguminous crops—beans, peas, clover, etc. An obvious explanation, therefore, which will be found in books of authority, is that these so distinguished "broad-leaved plants" have the power of taking up nitrogen in some form from the atmosphere, in a degree, or in a manner, not possessed by the narrow-leaved gramineous plants. It is true that Adolph Mayer in Germany, and Schlösing in France, have experimentally shown that plants can take up nitrogen by their leaves from ammonia supplied to them in the ambient atmosphere. But I think I am right in saying that the conclusion of both of these experimenters is that this action takes place in a very immaterial degree in natural vegetation.

In reference to this subject, I may observe that the results of the determinations of the ammonia in the atmosphere by different experimenters, and in different localities, vary very greatly; and it may be concluded that a shower of rain will wash out much of it. According to M. Schlösing's statement of the results of his recent determinations of the ammonia in the air of Paris (Compt. Rend., lxxxi, p. 1252 et seq.), it ranges from one part in about 12,500,000, to one part in about 260,000,000 of air by weight. If, for the purpose of illustration, we assume that, on the average, the ambient atmosphere in the open country—in Europe, at any rate—will contain one part of ammonia in 60,000,000 of air, or one part of nitrogen as ammonia in about 50,000,000 of air, the atmosphere would thus contain more than 8,000 times less nitrogen as ammonia than carbon as carbonic acid. But cereal crops contain one part of nitrogen to about thirty of carbon, and leguminous crops, one of nitrogen to fifteen, or fewer, of carbon. On these assumptions, the ambient atmosphere would contain a proportion of nitrogen as ammonia, to carbon as carbonic acid, about 267 times less than that of nitrogen to carbon in cereal produce, and about 534 times (or more) less than that in leguminous produce. It is true that water would absorb very much more nitrogen as ammonia, or dissolve very much more as carbonate or bi-carbonate of ammonia, than it would of carbon as carbonic acid under equal circumstances. Hence, there would appear to be a compensating quality for the small actual and relative amount of nitrogen as ammonia in the atmosphere, in the greater solubility or absorbability of the compounds in which nitrogen exists, than of the carbonic acid in which the carbon is presented. Further, it can hardly be to merely a greater extent of leaf or above-ground surface that the result could be attributed. Thus, though a bean and a wheat crop may yield about equal amounts of dry matter per acre, the bean produce would contain from two to three times more nitrogen, and approximate measurements show that a wheat plant offers a greater external superfices in relation to a given weight of dry substance than a bean plant, and greater still therefore in relation to a given amount of nitrogen fixed. If, then, the bean can in some way take up more nitrogen from the atmosphere than the wheat, the result must be due to character and function, rather than to mere extent of surface above ground. It may, however, be observed that, as a rule, even those of the leguminous crops which are grown for their ripened seed, maintain their green and succulent surface, over a more extended period of the season of active growth, than do the gramineous corn crops.

It may safely be asserted, then, that neither direct experimental evidence, nor a consideration of the chemistry and the physics of the subject, would lead to the conclusion that the plants which assimilate more nitrogen over a given area than others, do so by virtue of a greater power of absorbing by their leaves combined nitrogen from the atmosphere in the form of ammonia. And here it may be said in passing that the argument would be still stronger against the supposition that nitric acid in the atmosphere supplies directly to the leaves of plants any important amount of the nitrogen they assimilate.

But apart from the more purely scientific considerations bearing upon the question, we believe that our statistics of nitrogen-production are themselves sufficient to justify the conclusion that, at any rate, the "broad-leaved" *root-crops*, turnips and the like, to which the function has with the most confidence been attributed, do not take up any important proportion of their nitrogen by their leaves from combined nitrogen in the atmosphere. Thus, it has already been shown, that the yield of nitrogen in these crops, even with the aid of complex mineral manures, was in the later years reduced to a lower point than that in any other crop; the percentage of nitrogen in the upper layers of the soil was also reduced to a lower point than with any other crop. The evidence of this kind is, however, admittedly not so conclusive in regard especially to plants of the leguminous family.

Is the free nitrogen of the atmosphere the source of the assimilated nitrogen?—But as about four-fifths of the atmosphere which surrounds the leaves of plants consist of free nitrogen, why should not this be a source to them of the nitrogen they require? To assume that it is so is such an obvious and easy way out of so many difficulties, that this assumption has from time to time been freely made, and much experimental investigation has been undertaken on the point with the most conflicting results. It is now nearly forty years since Boussingault showed that there was a greater assimilation of nitrogen over a given area in a rotation of crops than he could well account for; and almost from that time to this he has been occupied with investigations of very various kinds, sometimes on the atmosphere, sometimes on meteoric waters, sometimes on plants, and sometimes on soils, the main object of which has obviously been to throw light on the question of the sources of the nitrogen of vegetation. And almost for as long a period as Boussingault, Mr. Lawes and myself have devoted much thought and investigation to the same end.

On this point, of whether or not plants assimilate the free nitrogen of the atmosphere, leaving out of view, for lack of time and space, the experiments and conclusions of several others who have worked on the subject on a less comprehensive scale, I will first briefly direct attention to the most comprehensive series of experiments, the results of which led the author to conclude that the free nitrogen of the atmosphere is taken up and assimilated by the leaves of plants.

During the years 1849, 1850, 1851, 1852, 1854, 1855, and 1856, M. G. Ville, of Paris, made numerous experiments on this subject. His plants were generally enclosed in a glass case, and his soils consisted of washed and ignited sand, sand and brick, or sand and charcoal. They were sometimes supplied with a current of unwashed air, sometimes with a current of washed air, and they were sometimes in free air; sometimes a known quantity of ammonia was supplied to the air of the apparatus, and sometimes known quantities of nitrate were supplied to the soil. Lastly, a great variety of plants were experimented upon. M. G. Ville's results are summarized in Table V, below.

TABLE V.—*Summary of the Results of* M. G. VILLE'S *Experiments, to determine whether Plants assimilate free Nitrogen.*

PLANTS.	Nitrogen—Grams.			Nitrogen in Products to 1 Supplied.
	In Seed, and Air; and Manure, if any.	In Products.	Gain or Loss.	
1849: *Current of unwashed air supplying* 0·001 *grams Nitrogen as Ammonia.**				
Cress	0·0260	0·1470	0·1210	5·6
Large Lupins	0·0640	0·0640	0·0000	1·0
Small Lupins	0·0640	0·0470	—0·0170	0·7
	0·1550	0·2580	0·1030	1·7
1850: *Current of unwashed air supplying* 0·0017 *grams Nitrogen as Ammonia.**				
Colza (plants)	0·0260	1·0700	1·0440	41·1
Wheat	0·0160	0·0310	0·0150	1·9
Rye	0·0130	0·0370	0·0240	2·8
Maize	0·0290	0·1380	0·0990	4·4
	0·0857	1·2660	1·1803	14·8
1851: *Current of washed air.**				
Sunflower	0·0050	0·1570	0·1520	31·4
Tobacco	0·0040	0·1750	0·1710	43·7
Tobacco	0·0040	0·1620	0·1580	40·5

* Recherches Expérimentales sur la Végétation, par M. Georges Ville. Paris, 1853.

TABLE V.—*Continued.*

PLANTS.	Nitrogen—Grams. In Seed, and Air; and Manure, if any.	Nitrogen—Grams. In Products.	Nitrogen—Grams. Gain or Loss.	Nitrogen in Products to 1 Supplied.
1852: *Current of washed air.**				
Autumn Colza	0·0480	0·2260	0·1780	4·7
Spring Wheat	0·0290	0·0650	0·0360	2·2
Sunflower	0·0160	0·4080	0·3920	25·5
Summer Colza	0·1730	0·5950	0·4220	3·4
Summer Colza	0·1050	0·7010	0·5960	6·7
1854: *Current of washed air (under superintendence of a Commission).*				
Cress	0·0099	0·0097	−0·0002	1·0
Cress	0·0038	0·0530	0·0492	13·9
Cress	0·0039	0·0110	0·0071	2·8
1854: *Current of washed air (closed, under superintendence of a Commission).*†				
Cress	0·0063	0·0350	0·0287	5·6
1855 and 1856: *In free air, with* 0·5 *grams Nitre* =0·069 *Nitrogen.*‡				
Colza	0·0700	0·0700§	0·0000	1·0
Colza	0·0700	0·0660§	−0·0040	0·9
Colza	0·0700	0·0680§	−0·0020	1·0
1855 and 1856: *In free air, with* 1 *gram Nitre* =0·138 *Nitrogen.*‡				
Colza	0·1400	0·1970§	0·0570	1·41
Colza	0·1400	0·3740§	0·2340	1·67
Colza	0·1400	0·2160§	0·0760	1·54
Colza	0·1400	0·2500§	0·1100	1·79
1856: *In free air, with* 0·792 *grams Nitre* =0·110 *Nitrogen.**				
Wheat	0·1260	0·2180§	0·0920	1·7
Wheat	0·1260	0·2240§	0·0980	1·8
1855: *In free air, with* 1·72 *grams Nitre* =0·238 *Nitrogen.**				
Wheat	0·2590	0·3080§	0·0490	1·2
1856: *In free air, with* 1·765 *grams Nitre* =0·244 *Nitrogen.**				
Wheat	0·2650	0·2170§	−0·0480	0·8
Wheat	0·2650	0·3500§	+0·0850	1·3

* Recherches Expérimentales sur la Végétation, par M. Georges Ville. Paris, 1853.

† Compt. rend., 1855. ‡ Recherches Expérimentales sur la Végétation, 1857.

§ In plants only.

We have already discussed the results of M. G. Ville, as well as those of others, in a paper published in the Philosophical Transactions for 1859, and in a somewhat condensed form in the Journal of the Chemical Society, vol. xvi, 1863; and we can only very briefly refer to them in this place. The column of actual gain or loss of nitrogen is seen to show in one case a gain of more than one gram of nitrogen; the amount of it in the products being more than forty-one fold that supplied as combined nitrogen in the seed, and air. This result was obtained with colza. Those obtained with wheat, rye, or maize, showed very much less of both actual and proportional gain. Experiments with sunflower and tobacco showed a less actual gain than that with colza; but still it amounted in one case, with sunflower, to more than thirty, and in two, with tobacco, to more than forty-fold of that supplied. In M. G. Ville's experiments (as a glance down the last two columns in the table will show), although he still had generally some gain, it was usually both actually and in proportion to the quantity supplied considerably less than in his earlier ones.

M. G. Ville attributed the gain, in some cases, to the large leaf-surface. In explanation of the assimilation of free nitrogen by plants, he calls attention to the fact that nascent hydrogen is said to give ammonia, and nascent oxygen nitric acid, with free nitrogen, and he asks, "Why should not the nitrogen in the juices of the plant combine with the nascent carbon and oxygen in the leaves?" He refers to the supposition of M. De Luca, that the nitrogen of the air combines with the nascent oxygen given off by the leaves of plants, and to the fact that the juice of some plants (mushrooms) has been observed to ozonize the oxygen of the air, and he asks, "Is it not probable, then, that the nitrogen dissolved in the juices will submit to the action of the ozonized oxygen with which it is mixed, when we bear in mind that the juices contain alkalies, and penetrate tissues, the porosity of which exceeds that of spongy platinum?"

The experiments of M. Boussingault, and of ourselves, on the other hand, have not given an affirmative answer to the question whether plants, by their leaves, take up and assimilate free nitrogen of the air.

M. Boussingault commenced his experiments on this subject in 1837, and Table VI, which follows, summarizes his results, obtained at intervals from that date up to 1858.

TABLE VI.—*Summary of the Results of* M. BOUSSINGAULT'S *Experiments, to determine whether Plants assimilate free Nitrogen.*

PLANTS.	Nitrogen—Grams.			Nitrogen in Products to 1 Supplied.
	In Seed, or Plants; and Manure, if any.	In Products.	Gain or Loss.	
1837: *Burnt soil, distilled water, free air, in closed summer-house.**				
Trefoil	0·1100	0·1200	+0 0100	1·09
Trefoil	0·1140	0·1560	+0·0420	1·37
Wheat	0·0430	0·0400	−0·0030	0·93
Wheat	0·0570	0·0600	+0·0030	1·05
1838: *Conditions as in* 1837.†				
Peas	0·0460	0·1010	+0·0550	2·20
Trefoil (Plants)	0·0330	0·0560	+0·0230	1·70
Oats (Plants)	0·0590	0·0530	−0·0060	0·90
1851 and '52: *Washed and ignited pumice with ashes, distilled water, limited air, under glass shade, with Carbonic Acid.*‡				
Haricot, 1851	0·0349	0·0340	−0·0009	0·97
Oats, 1851	0·0078	0·0067	−0·0011	0·86
Haricot, 1852	0·0210	0·0189	−0·0021	0·90
Haricot, 1852	0·0245	0·0226	−0·0019	0·92
Oats, 1852	0·0031	0·0030	−0·0001	0·97
1853: *Prepared pumice, or burnt brick, with ashes; distilled water, limited air, in glass globe, with Carbonic Acid.*‡				
White Lupin	0·0480	0·0483	+0·0003	1·01
White Lupin	0·1282	0·1246	−0·0036	0·97
White Lupin	0·0349	0·0339	−0·0010	0·97
White Lupin	0·0200	0·0204	+0·0004	1·02
White Lupin	0·0399	0·0397	−0·0002	1·00
Dwarf Haricot	0·0354	0·0360	+0·0006	1·02
Dwarf Haricot	0·0298	0·0277	−0·0021	0·93
Garden Cress	0·0013	0·0013	0·0000	1·00
White Lupin	0·1827	0·1697	−0·0130	0·93
1854: *Prepared pumice with ashes, distilled water, current of washed air, and Carbonic Acid, in glazed case.*§				
Lupin	0·0196	0·0187	−0·0009	0.95
Dwarf Haricot	0·0322	0·0325	+0·0003	1·01
Dwarf Haricot	0·0335	0·0341	+0·0006	1·02
Dwarf Haricot	0·0339	0·0329	−0·0010	0·97
Dwarf Haricot	0·0676	0·0666	−0·0010	0·99
Lupin	0·0180	} 0·0334	−0·0021	0.94
Lupin	0·0175			
Cress	0·0046	0·0052	+0·0006	1·13

* Ann. Ch. Phys., II, lxvii, (1838).
† Ibid., lxix.
‡ Ann. Ch. Phys., III, xli, (1854).
§ Ann. Ch. Phys., III, xliii, (1855).

TABLE VI.—*Continued.*

PLANTS.	Nitrogen—Grams.			Nitrogen in Products to 1 Supplied.
	In Seed, or Plants; and Manure, if any.	In Products.	Gain or Loss.	
1851, '52, '53, and '54: *Prepared soil, or pumice with ashes; distilled water, free air, under glazed case.**				
Haricot (dwarf), 1851	0·0349	0·0380	+0·0031	1·09
Haricot, 1852	0·0213	0·0238	+0·0025	1·12
Haricot, 1853	0·0293	0·0270	−0·0023	0·92
Haricot (dwarf), 1854	0·0318	0·0350	+0·0032	1·10
Lupin (white), 1853	0·0214	0·0256	+0·0042	1·20
Lupin, 1854	0·0199	0·0229	+0·0039	1·15
Lupin, 1854	0·0376	0·0387	+0·0020	1·05
Oats, 1852	0·0031	0·0041	+0·0010	1·32
Wheat, 1853	0·0064	0·0075	+0·0011	1·17
Garden Cress, 1854	0·0259	0·0272	+0·0013	1·05
1858: *Nitrate of Potassium as Manure.*†				
Helianthus	0·0144‡	0·0130	−0·0014	0·90
	0·0255‡	0·0245	−0·0010	0·96

M. Boussingault's soils consisted of burnt soil, washed and ignited pumice, or burnt brick; his experiments were sometimes in free air, sometimes in a closed vessel with limited air, sometimes with a current of washed air, and sometimes in free air, but under a glass case. When the plants were enclosed, a supply of carbonic acid was provided, and in a few cases known quantities of nitre were supplied as manure.

The last two columns of Table VI show the actual and proportional gain of nitrogen in M. Boussingault's experiments. It will be observed that in his earliest experiments, those in free air, in a summer-house, the leguminous plants, trefoil and peas, did indicate a notable gain of nitrogen; but in all his subsequent experiments there was generally either a slight loss, or, if a gain, it was represented in only fractions, or low units, of milligrams. After twenty years of varied and laborious investigation of the subject, M. Boussingault concluded that plants have not the power of taking up and assimilating the free nitrogen of the atmosphere.

Our own experiments on this subject were commenced in 1857, and the late Dr. Pugh, of the Pennsylvania State Agricultural College, devoted between two and three years to the investigation at Rothamsted. Mr. Lawes has contributed one complete set of the apparatus employed to this exhibition. The arrangement, and the results obtained up to that date,

* Ann. Ch. Phys., Sér. III, xliii, (1855). ‡ Compt. rend., xlvii, (1858).
‡ Nitrogren in seed and nitrate.

are fully described in the papers already referred to, published in the Philosophical Transactions for 1859, and in the Journal of the Chemical Society in 1863. They may be briefly described as follows:—

The soils used were ignited, washed, and re-ignited, pumice, or soil. The specially made pots were ignited before use, and cooled over sulphuric acid under cover. The pots, with their plants, were enclosed under a glass shade resting in the groove of a specially made hard-baked glazed stone-ware lute-vessel, mercury being the luting material. Under the shade, through the mercury, passed one tube for the admission of air, another for its exit, and another for the supply of water or solutions to the soil; and there was an outlet at the bottom of the lute-vessel for the escape of the condensed water into a bottle affixed for that purpose, from which it could be removed and returned to the soil at pleasure. A stream of water being allowed to flow into a large stone-ware Wolff's bottle (otherwise empty), air passed from it through two small glass Wolff's bottles containing sulphuric acid, then through a long tube filled with fragments of pumice saturated with sulphuric acid, and lastly through a Wolff's bottle containing a saturated solution of ignited carbonate of soda; and, after being so washed, the air enters the glass shade, from which it passes, by the exit tube, through an eight bulbed apparatus containing sulphuric acid, by which communication with the unwashed external air is prevented. Carbonic acid is supplied as occasion may require, by adding a measured quantity of hydrochloric acid to a bottle containing fragments of marble, the evolved gas being passed through one of the bottles of sulphuric acid, through the long tube, and through the carbonate of soda solution, before entering the shade.

It will be observed that, by the arrangement described, the washed air is forced, not aspirated, through the shade, and the pressure being thus the greater within the vessel, the danger of leakage of unwashed air from without inward is lessened. In 1857, twelve sets of such apparatus were employed; in 1858 a larger number, some with larger lute-vessels, and shades; in 1859 six, and in 1860 also six. The whole were arranged, side by side, in the open air, on stands of brick-work, as described in the papers referred to, and shown in the apparatus exhibited. Drawings of some of the plants grown were also exhibited, and the published results are summarized in Table VII.

TABLE VII.—*Summary of the Results of Experiments made at Rothamsted, to determine whether Plants assimilate Free Nitrogen.*

			Nitrogen—Grams.			Nitrogen in Products to 1 Supplied.
			In Seed, and Manure, if any.	In Plants, Pot and Soil.	Gain or Loss.	
With NO *combined Nitrogen supplied beyond that in the seed sown.*						
Gramineæ.	1857.	Wheat	0·0080	0·0072	−0·0008	0·90
		Barley	0·0056	0·0072	+0·0016	1·11
		Barley	0·0056	0·0082	+0·0026	1·46
	1858.	Wheat	0·0078	0·0081	+0·0003	1·04
		Barley	0·0057	0·0058	+0·0001	1·02
		Barley	0·0063	0·0056	−0·0007	0·89
	1858. A*	Wheat	0·0078	0·0078	0·0000	1·00
		Oats	0·0064	0·0063	−0·0001	0·98
Leguminosæ.	1857.	Beans	0·0796	0·0791	−0·0005	0·99
	1858.	Beans	0·0750	0·0757	+0·0007	1·01
		Peas	0·0188	0·0167	−0·0021	0·89
Other Plants.	1858.	Buck Wheat	0·0200	0·0182	−0·0018	0·91
WITH *combined Nitrogen supplied beyond that in the seed sown.*						
Gramineæ.	1857.	Wheat	0·0329	0·0383	+0·0054	1·16
		Wheat	0·0329	0·0331	+0·0002	1·01
		Barley	0·0326	0·0328	+0·0002	1·01
		Barley	0·0268	0·0337	+0·0069	1·25
	1858.	Wheat	0·0548	0·0536	−0·0012	0·98
		Barley	0·0496	0·0464	−0·0032	0·94
		Oats	0·0312	0·0216	−0·0096	0·69
	1818. A*	Wheat	0·0268	0·0274	+0·0006	1·02
		Barley	0·0257	0·0242	−0·0015	0·94
		Oats	0·0260	0·0198	−0·0062	0·76
Leguminosæ.	1858.	Peas	0·0227	0·0211	−0·0016	0·93
		Clover	0·0712	0·0665	−0·0047	0·93
	1858. A*	Beans	0·0711	0·0655	−0·0056	0·92
Other Plants.	1858.	Buck Wheat	0·0308	0·0292	−0·0016	0·95

The upper part of the table shows the results obtained in 1857 and 1858 in the experiments in which no combined nitrogen was supplied beyond that contained in the seed sown. The drawings show how extremely restricted was the growth under these conditions, and the figures in the table show that neither with the Gramineæ, the Leguminosæ, nor with buck-wheat, was there in any case a gain of three milligrams of

* These experiments were conducted in the apparatus of M. G. Ville.

nitrogen indicated. In most cases there was much less gain than this, or a slight loss. There was in fact nothing in these results to lead to the conclusion that either the Gramineæ, the Leguminosæ, or the buckwheat had assimilated free nitrogen.

The lower part of the table shows the results obtained in 1857 and 1858, in the experiments in which the plants were supplied with known quantities of combined nitrogen in the form of a solution of ammonium sulphate applied to the soil. The gains or losses range a little higher in these experiments, in which larger quantities of nitrogen were involved, but they are always represented by units of milligrams only, and the losses are higher than the gains. Further, the gains, such as they are, are all in the experiments with the Gramineæ, while there is in each case a loss with the Leguminosæ, and with the buckwheat. On this point it should be stated that the growth was far more healthy with the Gramineæ than with the Leguminosæ, which are even in the open fields very susceptible to the vicissitudes of heat and moisture, and were found to be extremely so when enclosed under glass shades. It might be objected, therefore, that the negative result, with the Leguminosæ are not so conclusive as those with the Gramineæ. However this may be, taking the results as they stand, there is nothing whatever in them to lead to the conclusion that either the Gramineæ or the Leguminosæ can take up and assimilate the free nitrogen of the atmosphere. We, indeed, do not hesitate to conclude from our own experiments, as Boussingault did from his, that the evidence is strongly against the supposition that plants can so avail themselves of the free nitrogen of the atmosphere.

Independently of the action suggested as possible by M. G. Ville, that is between free nitrogen and nascent or ozonized oxygen within the plant itself, it has been supposed that the free nitrogen of the atmosphere may unite with the nascent oxygen, or ozone, as the case may be, evolved by the plant, and so yield nitric acid. In our papers above referred to we have given reasons for supposing that such actions are not likely to take place; but whether they do or do not, it is at any rate certain that in our own experiments we have not been able to persuade plants to avail themselves of this happy faculty of producing their own nitrogenous food. With regard to the action supposed possibly to take place externally to the plant itself, if it were in any material degree operative, we should expect some, at least, of the resulting combined nitrogen to be collected in the aqueous deposits from the atmosphere; but we have seen how inadequate is the amount of combined nitrogen in those deposits to account for the yield of nitrogen, even of the Gramineæ, and still less can it satisfactorily explain the yield in the Leguminosæ and other plants.

[To be continued.]

The following conclusions are, I think, fairly deduced from the facts as noted in Colorado:

1st. In very early time in Colorado there was Archæan land rising above the Paleozoic sea. As the Carboniferous age progressed this land diminished by encroachment of the sea, due to subsidence of the land. This subsidence continued through Triassic, Jurassic, and Cretaceous time into the early Tertiary.

2d. At the close of the Lignitic there was a physical break followed by a subsidence (at least locally) and subsequently by elevation, after the deposition of the Miocene strata.

3d. The elevation of the Rocky Mountains as we now see them in Colorado, is the result of an elevation commencing in early Tertiary time, and continuing through the period, accelerated perhaps at the close of the Lignitic, and after the deposition of at least Lower Miocene strata.*

The elevation of the mountains was probably gradual as a general movement.

It is an interesting fact that Colorado has a higher mean elevation than any other State or Territory of the United States,† and that we find there the highest mass of mountains, and that the evidence points to the fact that in Paleozoic time also we had here one of the highest areas, thus confirming what Dr. Newberry has already intimated,‡ that the outlines of the western part of the North American Continent were outlined from earliest Paleozoic time.

ART. XXI.—*On some Points in connection with Vegetation*; by Dr. J. H. GILBERT.

[Concluded from page 111.]

Is the nitrogen combined under the influence of the soil with or without the aid of manures, the source of the assimilated nitrogen?—But if the plant itself cannot either assimilate free nitrogen, or effect its combination so as to bring it into a state for its use, may not such combination take place under the influence of the soil?

More than thirty years ago, Mulder argued that in the last stages of decomposition of organic matter in the soil, hydrogen was evolved, and that this nascent hydrogen combined with the free nitrogen of the air, and so formed ammonia.

* This elevation is probably going on at present also.

† List of Elevations, by H. Gannett, U. S. Geol. Survey, Miscel. pub. No. 1, 3d edition, p. 47.

‡ See Ives Exploring Expedition, Geol. Rep., p. 47, also p. 57 of Macomb's Exploring Expedition to the junction of Grand and Green Rivers.

A few years ago Dehérain substantially revived this view. He maintained that at a certain depth the air of the soil is poor in, or destitute of, oxygen; that hydrogen is evolved from the decomposing organic matter; that it unites with free nitrogen to form ammonia; and, that so, combined nitrogen increases in the soil in spite of the growth and removal of crops. This view he supports by some laboratory experiments.

It is obvious that if the reality of this action in soils were unquestionably established, it would greatly aid the solution of the question we are discussing. There, are, indeed, results of others on record which would seem to lend it probability.

Thus, Bretschneider found, on exposure of a mixture of humic acid and quartz sand to the air for a whole year, under conditions in which it was protected from rain and insects, that there was a gain of combined nitrogen which would represent an increase of more than 40 lbs. per acre.

Again, Boussingault exposed a moist garden soil for three months, and found a small gain of nitrogen. His explanation, was, however, different. He supposed it possible that ozone might be evolved in the oxidation of organic matter in the soil, and unite with free nitrogen, and so nitric acid be produced, and the soil gain in combined nitrogen. In other experiments Boussingault put mixtures of vegetable mould and pure sand in small quantities in large glass vessels which he perfectly closed and preserved in a dark cellar for a whole year. At the end of that period oxidation of organic matter had taken place, nitric acid was found, but there was upon the whole a small loss of combined nitrogen. Lastly in regard to Boussingault's results bearing upon this point, it has already been shown that in all of his experiments with plants in which his soils consisted of ignited pumice, ignited brick, or the like, without organic matter, he found no gain of combined nitrogen in soil and plant. In 1858 and 1859, however, he made a number of experiments on growth, in which part of the soil consisted of rich garden mould; and in two cases with lupins growing in confined air, and in one with haricot growing in free air, his results showed a notable gain of combined nitrogen: and although the quantity of garden mould employed was not the same in the three cases, the gain of nitrogen was approximately in proportion to the amount of soil used. The gain was, indeed, in the soil rather than in the plant. In the other experiments, however, either much less, or no gain was indicated.

Much more recently, Boussingault has published the results of experiments which showed that when a garden soil was confined for about eleven years in closed glass vessels in an atmosphere containing oxygen, the free nitrogen did not serve for the formation of nitric acid within it; but, on the contrary, the soil lost a portion of its combined nitrogen.

Since the delivery of this lecture, M. Berthelot (Compt. Rend., t. lxxxii, p. 1357) has stated that in experiments in which he exposed moistened cellulose to an electric current in an atmosphere of nitrogen, he found nitrogen taken up, and a fixed nitrogenous body formed. Referring to the last mentioned experiments of M. Boussingault, and his conclusions from them, M. Berthelot objects that the soils being in closed glass vessels, the intervention of atmospheric electricity was excluded, and the conditions of the experiments were, so far, unlike those of a natural soil.

Being very desirous to know the present opinion of M. Boussingault on the various points involved in this important question of the sources of the nitrogen of vegetation, I wrote to him shortly after undertaking to give this address, and asked whether he would be kind enough to favor me with a statement of his views on certain points. Unfortunately his reply did not reach me until after the delivery of the lecture; but, with his permission, I am now enabled to contribute a very valuable addition to the discussion in the form of a translation of the more essential parts of M. Boussingault's letter. He says:—

"(1.) In confined stagnant air, or in air moving through a closed apparatus, after previous purification, but still containing carbonic acid, plants growing in a soil destitute of nitrogenous manure, but containing the mineral substances indispensable for the vegetable organism, do not assimilate the nitrogen which is in a gaseous state in the atmosphere"

"(2.) In the open air, in a soil destitute of nitrogenous manure, but containing the mineral substances necessary for the vegetable organism, plants acquire very minute quantities of nitrogen, arising, no doubt from minute proportions of fertilizing nitrogenous ingredients carried by the air, ammoniacal vapors, and dust, always containing alkaline or earthy nitrates."

"(3.) In confined stagnant air, or in air renewed in a closed apparatus, a plant growing in a soil containing a nitrogenous manure, and mineral substances necessary for the vegetable organism, or in fertile vegetable earth, does not assimilate free nitrogen."

"(4.) In field culture, where dung is applied in ordinary quantities, analysis shows that there is more nitrogen in the crops than was contained in the manure applied."

"This excess of nitrogen comes from the atmosphere, and from the soil."

"(A.) From the atmosphere, because it furnishes ammonia in the form of carbonate, nitrates or nitrites, and various kinds of dust. Theodore de Saussure was the first to demonstrate the presence of ammonia in the air, and consequently in meteoric waters. Liebig exaggerated the influence of this ammonia on vegetation, since he went so far as to deny the utility of the nitrogen which forms a part of farm-yard manure. This influence is, nevertheless, real, and comprised within limits, which have quite recently been indicated in the remarkable investigations of M. Schlösing."

"(B.) From the soil, which, besides furnishing the crops with mineral alkaline substances, provides them with nitrogen, by ammonia, and by nitrates, which are formed in the soil at the expense of the nitrogenous matters contained in diluvium, which is the basis of vegetable earth; compounds in which nitrogen exists in stable combination, only becoming fertilizing by the effect of time. If we take into account their immensity, the deposits of the last geological period must be considered as an inexhaustible reserve of fertilizing agents. Forests, prairies, and some vineyards, have really no other manures than what are furnished by the atmosphere, and by the soil. Since the basis of all cultivated land contains materials capable of giving rise to nitrogenous combinations, and to mineral substances, assimilable by plants, it is not necessary to suppose that in a system of cultivation the excess of nitrogen found in the crops is derived from the free nitrogen of the atmosphere. As for the absorption of the gaseous nitrogen of the air by vegetable earth, I am not acquainted with a single irreproachable observation that establishes it; not only does the earth not absorb gaseous nitrogen, but it gives it off, as you have observed in conjunction with Mr. Lawes, as Reiset has shown in the case of dung, as M. Schlösing and I have proved in our researches on nitrification."

"If there is one fact perfectly demonstrated in physiology, it is this of the non-assimilation of free nitrogen by plants; and I may add by plants of an inferior order, such as mycoderms, and mushrooms."

Numerous experiments of Schlösing indicate a similar result to that last quoted of Boussingault. He selected a soil rich in humus, containing about 16 per cent of moisture, and 0·263 per cent of combined nitrogen. Known quantities of it were placed in large wide glass tubes, and during a period of about four months, he aspirated over them air containing respectively from 1·5 to 21 per cent of oxygen. He determined the carbonic acid in the air passing off, and the nitric acid in the soil before and after the experiment. He found that both the combustion of the organic matter, and the formation of nitric acid, were very considerable, even with the lowest proportion of oxygen in the air; but that the formation of the nitric acid in particular was very much the greater, the larger the proportion of oxygen in the air.

In a second set of experiments, he used the soil in a moister condition; and instead of the experiment in which the air contained only 1·5 of oxygen, he employed pure nitrogen; and the experiments extended over a period of about six months. In the case in which the aspirated air contained no oxygen, the whole of the nitric acid previously existing in the soil disappeared; but in the other cases there was a considerable formation of nitric acid.

In a third set of experiments, Schlösing determined the nitric acid in the soils, and added known quantities of potassium nitrate in a dilute solution. The mixture was enclosed in a flask of several times the capacity of the volume of soil. At the conclusion of the experiment only traces, if any, of gas containing hydrogen and carbon were present in the air of the vessel. The amount of ammonia in the soil increased considerably, but in only small proportion to that which the nitric acid would yield. At the end of the first experiment more potassium nitrate was added, and an atmosphere of known volume and composition supplied. At the conclusion of this experiment the soil contained no nitric acid; the amount of ammonia was increased, but again in only small proportion to the amount which the nitrate would yield. There was indeed a loss of total nitrogen in the soil.

Schlösing concludes that the combustion of organic matter in the soil is accompanied by a loss of nitrogen: that the combustion may be at the cost of the air as in the experiment of Boussingault, or at the cost of nitrates, of ferric oxide, or of the oxygen of organic matter, as in his own experiments.

It will be seen that on this important point of whether or not the soil may acquire combined nitrogen either in the form of ammonia by the combination of free nitrogen with nascent hydrogen evolved in the decomposition of organic matter in defect of oxygen, or in the form of nitric acid by the oxydation of free nitrogen, the evidence is, to say the least, conflicting. The more recent results of Boussingault, and those of Schlösing, would, however, indicate a greater probability of a loss of combined nitrogen, and evolution of free nitrogen.

Judging of the probabilities by reference to some of the results of our own investigations, we think that they are rather against than in favor of the supposition that there is any material gain of the kind assumed by Mulder and Dehérain. It may be well, however, briefly to call attention to some few facts which seem to bear upon the point, whether in favor, or otherwise, of the view in question.

The action assumed by Mulder and Dehérain, if it have place at all in soils in their natural condition, would be supposed, and is assumed, by Dehérain, to occur in layers sufficiently deep to be poor in oxygen. In the lower layers of the soil there is, however, a deficiency of carbonaceous organic matter also. Again, if such formation of ammonia do take place, it is probable that some at any rate of it must be oxidized into nitric acid; a condition which, on the other hand, implies an atmosphere not poor in oxygen. Thus, numerous results of analysis of the drainage water from many of the experimental plots at Rothamsted, to which further reference will be made presently, show that nearly the whole of the combined nitrogen in the drainage collected at a depth of about thirty inches, exists as nitrates and nitrites; which, obviously, would hardly be the case if the solution passed through a considerable layer of soil, the interstices of which contained an atmosphere poor in, or destitute of, oxygen.

Again, assuming such formation of ammonia to take place in the upper layers of the soil, where there is the most organic matter, and much oxidation of it, the supposition would be that the conditions would favor oxidation rather than the formation of ammonia from free nitrogen; and the fact of the formation of a good deal of nitric acid by the oxidation of nitrogenous organic matter, or ammonia, in the surface soil, is sufficiently established.

Further, if it were to the action assumed by Mulder and Dehérain taking place in the upper layers of the soil that we owe the supplies of combined nitrogen available to leguminous and other plants which assimilate so much more of it over a given area than the Gramineæ, the question may be asked—why cannot the Gramineæ avail themselves of this superficial supply? On this point it may be mentioned that, on some parts of the experimental wheat and barley fields at Rothamsted, farm-yard manure has been applied year after year, for a quarter of a century or more, in quantity containing perhaps six or seven times as much nitrogen as is removed in the increase of crop, and that thus the percentage of nitrogen in the surface soil has been more than doubled. Yet, as large a produce of barley, and a larger produce of wheat, is annually obtained by the use of very much smaller quantities of nitrogen, as ammonia-salts or nitrate. It would thus appear that the nitrogen of the farm-yard manure was only available to the cereals after its transformation into ammonia or nitric acid. Unfortunately, we are not at present able to adduce direct experimental evidence as to the condition in which the large amount of inefficient nitrogen exists in the soil, or as to whether a leguminous crop would or would not grow luxuriantly in it, but there is little doubt that it would do so. On the other hand, a good crop of clover would appear to be attainable in soil comparatively poor in nitrogen in its upper layers, and comparatively poor in organic matter also; for, in the experiments already referred to in which barley was grown after barley and after clover, the large amount of clover obtained, and nitrogen assimilated in it, was after six corn crops grown by artificial manure alone; conditions under which the amount, both of available nitrogen, and of organic matter, in the upper layers of the soil, would be supposed to be comparatively small.

The answer of Dehérain would probably be, that under the circumstances supposed, the nitrogen would be in a condition of combination not favorable for assimilation by the Gramineæ; that, in fact, the ammonia formed would combine with organic acids in the soil, yielding compounds specially favorable as food for the Leguminosæ. An objection to this view is, that if the accumulation in the soil by time, of nitrogen in a condition specially favorable for the Leguminosæ were such as is here assumed, we should expect the amount of nitrogen in the soil, determinable by the soda-lime process, to be higher before than after the growth of a leguminous crop; whereas, on the contrary, after the growth of a leguminous crop, the amount of nitrogen so determinable in the upper layers of the soil is very appreciably increased.

The evidence in favor of the supposition that the special source of nitrogen to the Leguminosæ is ammonia, or other compounds than nitric acid, in the upper layers of the soil, is then, to say the least, inconclusive. It remains to consider whether it may not be nitric acid, either in the soil or in the subsoil?

As already said, there is abundant evidence of the formation and existence of a considerable amount of nitric acid in surface soils; even in such as contain a relatively high amount of carbonaceous and nitrogenous organic matter. For example, a soil at Rothamsted which has been under garden cultivation, and as such probably manured almost every year for centuries, has successfully grown clover every year for more than twenty years. This soil was shown by the late Dr. Pugh, and has been again recently by Mr. Warington, to contain a considerable amount of nitric acid. But such a soil would, there is no doubt, grow large crops of Gramineæ also; which direct experiments show to attain great luxuriance under the influence of artificially applied nitrates. But such a rich garden soil contains an abundance of every thing—mineral constituents, carbonaceous organic matter, and combined nitrogen in various forms, and thus the exact conditions which it supplies favorable to the Leguminosæ cannot at once be discriminated.

The fact of the comparatively little, or at least uncertain action of directly applied nitrates on the growth of the Leguminosæ, would seem to be inconsistent with the supposition that it is the nitric acid in such a surface soil that has given it its special adaptation for the growth of clover for so many years—unless, indeed, it be the case, that it is much more available to such crops when in combination with some bases than with others.

The next point to consider is, whether there are any facts in favor of the supposition that clover, and leguminous crops generally, acquire any material proportion of their nitrogen in lower layers, and in a more extended range of the soil, than the Gramineæ. As an element in the discussion of this question, it will be well in the first place to call attention to the effects of direct nitrogenous manures, such as ammonia-salt, or nitrates, on the growth of some of our crops.

In Table VIII is shown the estimated amounts of carbon, yielded per acre per annum, in wheat over twenty years, in barley over twenty years, in sugar-beet over three years, and in beans over eight years; each with a complex mineral manure alone, and each with the same mineral manure and given quantities of nitrogen in addition, supplied in some cases in the form of ammonia-salts, and in others as nitrate. The gain of carbon by the use of the nitrogenous manure is also given.

TABLE VIII.—*Estimated yield and gain of Carbon per acre, per annum, in experimental Crops at Rothamsted.*

Manuring, Quantities per acre, per annum.	Average Carbon per acre, per annum. Actual	Gain.
Wheat 20 *years*, 1852–1871.		
	lbs.	lbs.
Complex Mineral Manure	988	
Complex Min. Man. and 41 lbs. nitrogen, as ammonia	1590	602
Complex Min. Man. and 82 lbs. nitrogen, as ammonia	2222	1234
Complex Min. Man. and 82 lbs. nitrogen, as nitrate	2500	1512
Barley 20 *years*, 1852–1871.		
Complex Mineral Manure	1138	
Complex Min. Man. and 41 lbs. nitrogen, as ammonia	2088	1150
Sugar-Beet 3 *years*, 1871–1873.		
Complex Mineral Manure	1136	
Complex Min. Man. and 82 lbs. nitrogen, as ammonia	2634	1498
Complex Min. Man. and 82 lbs. nitrogen, as nitrate	3081	1945
Beans 8 *years*, 1862 *and* 1864–1870.		
Complex Mineral Manure	726	
Complex Min. Man. and 82 lbs. nitrogen, as nitrate	992	266

It is quite evident that in the case of the gramineous crops, wheat and barley, which contain a comparatively low percentage of nitrogen, and assimilate a comparatively small amount of it over a given area, and also in that of the sugar-beet. there was a greatly increased amount of carbon assimilated by the addition of nitrogenous manure alone. In the case of the wheat, there is much more effect from a given amount of nitrogen supplied as nitrate, which is always applied in the spring, than from an equal quantity as ammonia-salts, which are applied in the autumn, and are subject to winter drainage. There is also more effect from ammonia-salts applied to barley than to wheat; the application being made for the former in the spring and for the latter in the autumn. There is again more effect from the nitrate than from the ammonia-salts when applied to sugar-beet, the application being made in both cases at the same date, in the spring.

On the other hand, the effect of the nitrogenous manure upon the highly nitrogenous bean crop is seen to be, comparatively, very insignificant.

In reference to this point, it should be observed that there has been this greatly increased assimilation of carbon in the wheat and in the barley for more than twenty years, without the addition of any carbon to the soil. It is indeed certain that, in the existing condition of our soils, the increased growth of our staple and starch-yielding grains is greatly dependent on a supply of nitrogen to the soil. It is equally certain that the increased production of sugar in the gramineous sugar-cane, in the tropics, is likewise greatly dependent on the supply of nitrogen to the soil.

In reference to the great increase in the assimilation of carbon in the sugar-beet by the use of purely nitrogenous manures, it may be of interest to observe that over the three years of the experiments with sugar-beet, the increased production of sugar per acre per annum was about 20 cwts. by the use of 82 lbs. of nitrogen per acre per annum as ammonia-salts, and about 28 cwts. by the use of 82 lbs. of nitrogen as nitrate of soda.

It is then our characteristically starch and sugar-producing crops that are the most characteristically benefited by the application of nitrogenous manures; while our highly nitrogenous leguminous crops are comparatively little benefited by such manures.

Proportion of nitrogen of manure got back by the increase of crops.—But now let us consider what is the proportion of the nitrogen supplied in manure that we get back in the increase of the crops that are most specially benefited by its use?

In Table IX is shown the amount of nitrogen recovered, and the amount not recovered, in the increase of crops for 100 supplied in manure, to wheat, and to barley, respectively; the result being in each case the average over a period of twenty years.

TABLE IX.—*Nitrogen recovered, and not recovered, in the increase of Produce, for 100 supplied in Manure.*

Manuring, quantities per acre, per annum.	For 100 Nitrogen in Manure. Recovered in Incr'se.	For 100 Nitrogen in Manure. Not Recovered in Incr'se.
Wheat 20 *years*, 1852–1871.		
Complex Min. Man. and 41 lbs. nitrogen, as ammonia	32·4	67·6
Complex Min. Man. and 82 lbs. nitrogen, as ammonia	32·9	67·1
Complex Min. Man. and 82 lbs. nitrogen, as nitrate	45·3	54·7
Barley 20 *years*, 1852–1871.		
Complex Min. Man. and 41 lbs. nitrogen, as ammonia	48·1	51·9

Speaking generally, it may be said that, nothwithstanding the great effects produced by the nitrogenous manures, two-thirds of the nitrogen supplied were unrecovered in the increase of crop when the ammonia-salts were applied to wheat; the application being made in the autumn. When, however, nitrate of soda was used, which is always applied in the spring, the quantity left unrecovered was not much more than half that supplied. With barley also, the manuring for which takes place in the spring, there is again nearly half the nitrogen supplied in the manure recovered in the increase, and therefore little more than half left unrecovered.

It may be observed that, in the case of root-crops, when the supply of nitrogen is not excessive, the proportion of the nitrogen of the manure recovered in the increase may be much greater than in the case of the cereals; while in the case of the Leguminosæ the effects of such direct application of soluble nitrogenous manures to the surface soil is comparatively so small, and so uncertain, that it would be useless to give an estimate of the amounts recovered and not recovered respectively.

But what becomes of the one-half or two-thirds of the nitrogen supplied for the increased growth of the cereals, but not recovered in the increase of crop? Dr. Frankland and Dr. Voelcker have made numerous analyses of the drainage water from the experimental wheat plots which have yielded the results above referred to, and a summary of their results is given in Table X.

TABLE X.—*Nitrogen as Nitrates and Nitrites, per* 100,000 *parts of Drainage Water from Plots differently manured, in the Experimental Wheat Field at Rothamsted, Wheat every year, commencing* 1844.

Manuring, Quantities per acre, per annum.	Nitrogen as Nitrates and Nitrites, per 100,000 parts Drainage Water.					
	Dr. Frankland's Results.		Dr. Voelcker's Results.		Mean.	
	Experiments.		Experiments.		Experiments.	
Farm-yard Manure	4	0·922	2	1·606	6	1·264
Without Manure	6	0·316	5	0·390	11	0·353
Complex Mineral Manure	6	0·349	5	0·506	11	0·428
Complex Min. Man. and 41 lbs. nitrogen, as ammonia	6	0·793	5	0·853	11	0·823
Complex Min. Man. and 82 lbs. nitrogen, as ammonia	6	1·477	5	1·400	11	1·439
Complex Min. Man. and 123 lbs. nitrogen, as ammonia	6	1·951	5	1·679	11	1·815
Complex Min. Man. and 82 lbs. nitrogen, as nitrate	5	1·039	5	1·835	10	1·437

The figures in the Table conclusively show that the quantity of nitrogen as nitrates per 100,000 parts of the drainage water, increased in very direct proportion to the increase in the amount of ammonia or nitrate supplied, and it is obvious that there has been a considerable loss of the nitrogen of the manures by drainage. But as the subsoil rests upon chalk not many feet below the surface, and there is, therefore, natural drainage constantly going on, even when there is no flow from the pipes, it is impossible accurately to estimate the total amount of drainage, and therefrom the total amount of loss. Other experiments at Rothamsted, however, lead to the conclusion that, according to season, from one-quarter to nearly one-half of the annual rainfall may pass below 40 inches. Now, supposing drainage water to contain one part of nitrogen as nitrates per 100,000 parts of water, an inch of rain passing beyond the reach of the roots would carry with it 2¼ lbs. of nitrogen per acre; and it is obvious that if from seven to ten inches passed annually of that average strength, the loss would be very great. In reference to this point it is of much interest to observe, that in the Report of the River's Pollution Commission already referred to, Dr. Frankland gives a series of analyses of land drainage waters collected at Rothamsted, at depths of twenty, forty, and sixty inches, respectively; and those collected at twenty inches, almost invariably show much more nitrogen as nitric acid than those taken at either forty or sixty inches. It would thus appear to be indicated that a considerable amount of nitric acid has been arrested in the soil below the depth of twenty inches. Further, determinations of nitrogen in the soils do show some accumulation. Indeed, it would appear probable, that the whole of the nitrogen applied to the wheat as ammonia salts or nitrate of soda, was either recovered in the increase of crop, or may be accounted for by determinable accumulation within the soil, or by loss by drainage.

In ordinary agriculture, the amounts of soluble nitrogenous manures applied would generally be much less than in some of these special experiments; and the losses by drainage would from that cause alone be proportionately less than that shown above. Much, obviously, would also depend upon the character of the soil and of the subsoil. Again, in an ordinary rotation of crops, more of the supplied nitrogen would probably be gathered up before it reached the lower layers, than in the case of a cereal crop grown year after year on the same land. It may be safely concluded, however, that whenever cereals were grown, a material proportion of the nitrogen specially applied to, or existing in the soil, which would be available to other crops, would not be so to them; but would in the first instance accumulate in the surface soil, and gradually pass into the lower layers in the form of nitrates, to be eventually lost by drainage if not arrested by some other crop.

The question obviously arises, whether we have not here a source of some at least of the nitrogen available to leguminous or to other plants having possession by their roots of a greater range of subsoil than the Gramineæ. We have evidence enough that although wheat and barley send roots down very deep into the subsoil, and pump up moisture from the deeper layers, they nevertheless derive much of their nitrogen within the surface soil. If the Leguminosæ do not so readily do so, or at any rate naturally depend more upon the nitrogen in the lower layers for a considerable proportion of that which they require, and moreover are able to avail themselves of the residue from the manuring for other crops, what is the nature of the problem that we may have to solve to elucidate this point?

By way of illustration it may be mentioned that, supposing a leguminous crop to acquire 100 lbs. of nitrogen per acre from a layer of subsoil three feet in thickness, weighing approximately 10,000,000 lbs. (exclusive of stones and water), this would represent only ·001 per cent of nitrogen so acquired in such subsoil; 200 lbs. of nitrogen per acre so available would represent ·002 per cent, and so on. Now, even supposing that the nitrogen existed in the subsoil in such a condition as to be converted into ammonia in the process of combustion with soda-lime, the difference between one subsoil containing this, or even a larger amount of nitrogen, more than another, could not with certainty be determined by that process; for, in taking say 15 or 20 grams of the subsoil for combustion, the difference between two or more determinations could not be expected to be less than some units in the third decimal place (per cent); that is, in fact, equal to the total amount that may be in question as between two subsoils to be compared. Further, if this available nitrogen exist in the subsoil as nitrates, it may be a question whether there would be a sufficient amount of organic matter present to insure the evolution as ammonia of the nitrogen of the nitric acid.

It has been shown, then, that there are many questions still open for investigation in regard to the relations of the surface soil to combined nitrogen; and there are obviously also equally important points to investigate in regard to the nitrogen of the subsoil, before we can hope to arrive at a satisfactory solution of some of the problems which the consideration of the facts of vegetable production which have been adduced, suggest for enquiry. Nor are the problems still open connected with the amount, and the condition, of the mineral food of plants within the soil, either few, or without special, and independent interest. And although those relating to the nitrogen seem to call for the first attention, the marked effects, so far, of potash manures, in increasing the amount of nitrogen assimilated over a given area by the Leguminosæ, seem to indicate the probability that even the difficulties connected with the sources of the nitrogen of our crops may not be solved without further knowledge as to the required conditions, or the actions, of the incombustible or mineral constituents in soils.

More extended investigation required.—Our results in regard to the variations in the amount of nitrogen in the soils and subsoils of our different experimental plots, obtained by the soda-lime process, together with the results already referred to, relating to the composition of the drainage water from plots variously manured, as well as others of quite a different kind, have shown the absolute necessity for an extended investigation of the soil question by more exact methods; and Mr. Warington is about to devote, probably some years, to this enquiry at Rothamsted. It is proposed that the questions relating to the nitrogen in subsoils should be the first considered, since, if the results do throw light upon some of the points at present in doubt, a definite step in advance will be so gained; and should they not do so, the ground will thus be cleared of certain obvious suppositions, and the course of further research will be the more clearly indicated. But if the amount of nitrogen to be discriminated should prove to be represented by only units in the third decimal place per cent, say ·002 for example, it is obvious that to get as little as four milligrams involved in the analysis. 200 grams of soil would have to be operated upon. The difficulties of the problem are thus sufficiently obvious. But, by the aid of the processes of water and gas analysis which have been explained by the President in his opening address, there is little doubt that they can be overcome, at any rate so far as the nitrogen existing as nitric acid is concerned; and by the kindness of Dr. Frankland, Mr. Warington is at the present time gaining experience in the use of those methods, in the laboratory of the College of Chemistry, before entering upon this special investigation at Rothamsted.

But even supposing we arrive at a satisfactory solution of the, at present, unsettled points in regard to the sources of the nitrogen yielded in agricultural production, when, as in the experiments to which attention has been directed, we have a soil to work upon which already contains accumulations of combined nitrogen amounting to several thousands of pounds per acre within the range of the roots of our crops, further questions in regard to the nitrogen may still be left open, namely,—to what actions a large proportion of the existing combined nitrogen may be attributed; and what in particular is the exact source of the accumulations of it in our soils and subsoils? And here it may be observed, in passing, that determinations made at Rothamsted have shown approximately the same percentage of nitrogen in the Oxford-clay obtained in the recent Sub-Wealden exploration boring at a depth of 500 and 600 feet, and in the subsoil at Rothamsted, taken a depth of about 4 feet only.

It is not within the scope of the present discourse to discuss fully what is known of the actual or possible sources of the already existing combined nitrogen, the special object of the enquiry being, as intimated at the commencement, to bring to view the facts relating to the yield of nitrogen in agricultural production, which the extended period of the investigations of Mr. Lawes and myself have enabled us to establish, and to point out the relation of this to the various known or supposed sources of present periodic supplies, so as to indicate what points seem the most urgently to demand further investigation. In the papers already referred to, we have more fully considered what was known of the various actual or possible sources of the combined nitrogen which we know to exist, and to circulate, in land and water, in animal and vegetable life, and in the atmosphere, and we have pointed out how little was established of either the actual or the relative importance, in a *quantitative* sense, of the various actions by which it is admitted that free nitrogen may in nature be brought into combination. I may, however, observe that M. Boussingault and M. Schlösing have quite recently made interesting contributions to the discussion of this subject. (Compt. Rend., t. lxxvi, lxxx, lxxxi, and lxxxii).

But whatever may be the origin of the existing combined nitrogen, or whether or not the agencies of its formation are more or less active now than during the earlier history of the earth