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RESULTS OF EXPERIMENTS AT ROTHAMSTED,
ON THE
GROWTH OF
LEGUMINOUS CROPS,

FOR MANY YEARS IN SUCCESSION
ON THE SAME LAND ;

BEING

(WITH ADDITIONS)

A LECTURE DELIVERED NOVEMBER 1, 1889,

AT THE

ROYAL AGRICULTURAL COLLEGE,
CIRENCESTER,

BY

J. H. GILBERT, M.A., LL.D., F.R.S.,

SIBTHORPIAN PROFESSOR OF RURAL ECONOMY
IN THE UNIVERSITY OF OXFORD,

AND

HONORARY PROFESSOR OF THE COLLEGE.

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RESULTS OF EXPERIMENTS AT ROTHAMSTED, ON
THE GROWTH OF LEGUMINOUS CROPS,
FOR MANY YEARS IN SUCCESSION ON THE SAME LAND.

INTRODUCTION.

The subject of my lecture to-day is—the conditions, and the results of growth, of Leguminous Crops ; and, as on former occasions, I propose to draw my illustrations largely from the results of field experiments, and other investigations, conducted at Rothamsted.

In former lectures I have, in a similar way, considered the conditions and the results of growth—of Wheat, and of Barley, as representatives of the great gramineous family ; of some varieties of Turnips, representing the *Cruciferae* ; of some varieties of Beet, representing the *Chenopodiaceae* ; and of Potatoes, of the *Solaneae*.

It was found that, within certain limits, the requirements, and the results of growth, of different members of one and the same family, showed certain characteristics in common ; whilst those of different families showed more or less of distinctive character. Nevertheless, there are some important points of similarity, as well as of contrast, between the requirements of the agricultural representatives of the *Gramineae*, the *Cruciferae*, the *Chenopodiaceae*, and the *Solaneae*.

It will be seen, however, that the agricultural representatives of the *Leguminosae*, all of which are included in the sub-order *Papilionaceae*, and some of which are of much importance in our agriculture, show very marked differences, as compared with those of any of the other families I have enumerated.

It so happens that, both the scientific interest, and the practical value, of these crops, whether as elements in rotation, or as grown in the mixed herbage of grass-land, depend very largely on the amount of nitrogen which they contain, and on the sources of their nitrogen ; and especially on the great differences in these respects, between them, and the representatives of the other families with which they are grown, either in alternation in our rotations, or in association in our meadows and pastures.

So much is this the case, that it is essential to a proper understanding and appreciation, of the characteristics of growth of these crops, and for the illustration of their value and importance as depending on those characteristics, to compare and to contrast the conditions and results of their growth, with those of the crops of other families.

I will first call attention to the difference in the amounts of nitrogen assimilated over a given area by different crops, when each is grown

for many years in succession on the same land, without any nitrogenous manure; or when grown in alternation one with another, also without nitrogenous manure; that is to say, under conditions in which the soil is to a great extent exhausted of accumulations of nitrogen due to recent supplies by manure, and when, therefore, the plants have to rely largely on what may be called the natural resources of the soil, and on those of the atmosphere.

I shall next show the effects of artificial supplies of nitrogen, on the growth of the different descriptions of plant, on the amount of nitrogen they assimilate, and on the amount and character of their products.

Lastly, I shall adduce evidence of quite other kinds, as to the sources of the nitrogen, more especially of the *Leguminosæ*; a question which has been the subject of experimental enquiry, and at times of active controversy, for about half a century; which has in recent years assumed a somewhat new aspect; but which cannot even yet be said to be conclusively settled.

YIELD OF NITROGEN PER ACRE PER ANNUM IN DIFFERENT CROPS, WITHOUT NITROGENOUS MANURE.

Table I. (p. 3), shows the yield of nitrogen per acre per annum, with mineral, but without any nitrogenous manure—in Wheat and in Barley as *Gramineous* crops, in Turnips as representatives of the *Cruciferae*, in Sugar-Beet and Mangel-Wurzel of the *Chenopodiaceæ*, and in Beans and Clover as *Leguminous* crops, when each is grown for many years in succession on the same land. It also shows, the amounts of nitrogen yielded per acre, when Turnips, Barley, a Leguminous crop, and Wheat, are grown in an actual course of rotation, also with mineral, but without nitrogenous manure.

Incidentally it is to be noticed that, in the case of each of the crops—Wheat, Barley, and Beans—thus grown year after year on the same land for many years in succession without nitrogenous manure, there was a reduction in the yield of nitrogen per acre per annum, over the second period compared with the first; that is, as the accumulations within the soil became reduced.

Disregarding this tendency to reduced yield, it is seen that, over the same period of 24 years, with full mineral but without nitrogenous manure, the wheat yielded an average of 22.1 lbs., and the barley 22.4 lbs. of nitrogen per acre per annum; the two allied crops, therefore, yielding almost identical amounts, in their above-ground produce, without nitrogenous manure, on soil very poor in available nitrogen, so far as accumulations due to recent applications of nitrogenous manure are concerned.

Turning now to the yield of nitrogen in the root-crops,—Turnips, Sugar-Beet, and Mangel-Wurzel—it may be mentioned that, prior to the period referred to in the Table, Turnips had been grown for a number of years, and had yielded 42 lbs. of nitrogen per acre per

annum, due to the accumulations from comparatively recent nitrogenous manuring. But, it is seen that, after these accumulations had been reduced, Swedish Turnips gave over 15 years, an average of only 18·5 lbs., Sugar-Beet over the next 5 years, an average of only 14·7 lbs., and Mangel-Wurzel over the succeeding 10 years, an average of only 14·0 lbs. of nitrogen, per acre per annum. Or, reckoned over the whole period of 30 years, after the recent accumulations had been worked out, the root-crops gave an average of only 16·4 lbs. of nitrogen per acre per annum.

TABLE I.

Nitrogen per acre per annum, in various Crops grown at Rothamsted, with Mineral, but without Nitrogenous Manure.

							Duration of Experiment.	Average Nitrogen per acre per annum.
								lbs.
Wheat	..	..	..	..	..	}	12 years, 1852-1863	27·0
							12 years, 1864-1875	17·2
							24 years, 1852-1875	22·1
Barley	..	..	..	..	}	12 years, 1852-1863	26·0	
						12 years, 1864-1875	18·8	
						24 years, 1852-1875	22·4	
Root-crops	{	Swedish Turnips	..	..			*15 years, 1856-1870	18·5
		Sugar Beet	..	..	..		5 years, 1871-1875	14·7
		Mangels	..	..	..		10 years, 1876-1885	14·0
		Total			..	..	30 years, 1856-1885	16·4
Beans	..	..	..	..	}	12 years, 1847-1858	61·5	
						†12 years, 1859-1870	29·5	
						24 years, 1847-1870	45·5	
Clover	..	..	..	..	..	‡22 years, 1849-1870	39·8	
Rotation (8 courses)	{	1. Swedish Turnips	..	..		}	32 years, 1852-1883	33·3
		2. Barley	..	..				23·5
		3. { Clover (2 courses)	..	..				124·5
		{ Beans (6 courses)	..	..				40·5
		Average Clover and Beans						61·5
		4. Wheat	..	..				35·9
Average all Crops			..			38·6		

* 13 years crop, 2 years failed.

† 9 years beans, 1 year wheat, 2 years fallow.

‡ 6 years clover, 1 year wheat, 3 years barley, 12 years fallow.

§ Superphosphate only.

It is remarkable, how very similar is the amount of nitrogen annually accumulated in Gramineous, Cruciferous, and Chenopodiaceous crops, after the soil had been exhausted of the more recent and more

readily available nitrogenous accumulations. Thus, over the second half of the period, the Wheat gave 17·2, and the Barley 18·8 lbs., against 16·4 lbs. over 30 years in the various root-crops.

We now come to the yield of nitrogen in Leguminous crops, grown under somewhat similar circumstances as to the soil supplies of it. Referring first to the results obtained with Beans, it is seen that, over the first half of the period of 24 years, the average annual yield of nitrogen in the crop was 61·5 lbs. per acre; whilst, over the second 12 years, in 3 of which, however, the crop failed, so that there were only 9 years of Beans, 1 year of Wheat, and 2 years of Fallow, the annual yield was less than half as much, or only 29·5 lbs. per acre. Nevertheless, the average yield over the 24 years without any nitrogenous manure, was 45·5 lbs. per acre per annum. That is to say, under very similar conditions as to soil supply, the highly nitrogenous Leguminous crop, Beans, has yielded over a given area, twice as much nitrogen as either Wheat or Barley, and more than twice as much as the root-crop.

The next results relate to the Leguminous crop, Clover. It is well known that Clover fails when it is attempted to grow it too frequently on the same land; and in the case recorded in the Table, it happened that Clover was obtained in only 6 years out of the 22 for which the yield of nitrogen is given; so that there are included, owing to the failures, 1 year of Wheat, 3 years of Barley, and 12 of Fallow. Notwithstanding this, there was, with the occasional interpolation of the Clover, an average yield, over the 22 years, of 39·8 lbs. of nitrogen per acre with mineral, but without nitrogenous supply.

The last results in the Table relate to the yield of nitrogen per acre per annum, over 32 years of an actual rotation of crops; that is, over 8 courses of 4 years, each course comprising Swedish Turnips, Barley, Clover (or Beans), and Wheat, which, as in the other cases, were grown with a purely mineral manure (in this case superphosphate of lime alone), but without any nitrogenous supply.

The figures show that, when the various crops are thus grown in alternation one with another, instead of each separately year after year, on the same land, the yield of nitrogen is generally greater, and sometimes much greater. Thus, whilst the mineral manured Swedish Turnips, yielded only 18·5 lbs. of nitrogen per acre per annum, when grown year after year on the same land, they yielded 33·3 lbs. when grown in rotation; the Barley yielded 22·4 lbs. when grown continuously, and 23·5 lbs. in rotation; the Beans 45·5 lbs. grown year after year, and only 40·5 lbs. in rotation, but this is very much more than the yield of the continuous Beans in the second half of the period, which was only 29·5 lbs.; the Clover yields an average of 124·5 lbs. in rotation, against only 39·8 lbs. when it was attempted to grow it continuously, and it frequently failed; and the Wheat succeeding the Leguminous crop in rotation, yields 35·9 lbs. against only 22·1 lbs. grown continuously. Lastly, the rotation crops taken together (including *Leguminosæ*), have yielded, over 32 years, an average of 38·6 lbs. of nitrogen per acre per annum, against only about half as much in either

Wheat, Barley, or Roots, grown under the same manurial conditions, that is without nitrogenous supply, but each grown continuously on the same land ; whilst, in an exactly corresponding rotation, but with fallow instead of a leguminous crop in the third year, the average annual yield of nitrogen over the 32 years, was only 24·3 lbs.

It is seen, then, that the increased yield of nitrogen in the rotation-crops, was largely due to the interpolation of the *Leguminosæ*, the Clover or the Beans ; in part owing directly to the large yields of nitrogen in these crops themselves, but in part to the increased yields in the Wheat immediately succeeding the Leguminous crop, which, especially the Clover, would leave an effective nitrogenous crop-residue, but, in part also, to some effect from this increased crop-residue on the other crops of the course ; and lastly, to the fact, that the various crops grown in alternation have different root ranges, and grow during different periods of the season. The Wheat, in fact, yielded nearly as much after the removal of the highly nitrogenous Leguminous crop, as on a corresponding plot left Fallow ; from which, therefore, no nitrogen had been removed in the produce in the preceding year.

The next illustrations show more strikingly still, the greater yield of nitrogen in Leguminous than in Gramineous crops, grown under equal soil conditions. They relate to the yield of nitrogen in Barley and in Clover, grown side by side in the same field ; and the results are given in Table II.

TABLE II.

Nitrogen per acre per annum, in Barley and Clover, grown in Little Hoosfield, Rothamsted.

										Nitrogen per acre.
										lbs.
1873	Barley	..	..	..	..	..	..	..	..	37·3
	Clover	..	..	..	..	..	..	..	..	151·3
1874	Barley	{ After Barley	..	..	..	..	..	..	..	39·1
		{ After Clover	..	..	..	..	..	..	..	69·4
	Barley after Clover more than after Barley									30·3

The field had grown one crop of Wheat, one crop of Oats, and three crops of Barley in succession with artificial mineral and nitrogenous manures, but without any farm-yard or other organic manure. In 1872, Barley was again sown ; on one half alone, and on the other half with Clover. In 1873, Barley was again grown on the one half, but the Clover on the other. The Table shows that the Barley yielded 37·3 lbs. of nitrogen per acre, whilst the three cuttings of Clover contained 151·3 lbs. In the next year, 1874, Barley was grown over both portions : and on the one where Barley had yielded 37·3 lbs. of nitrogen in the previous year, it now yielded 39·1 lbs. ; but on the portion where the Clover had yielded 151·3 lbs., the Barley succeeding it yielded 69·4 lbs. That is to say, the Barley yielded 30·3 lbs. more

nitrogen after the removal of 151·3 lbs. in Clover, than after the removal of only 37·3 lbs. in Barley.

The fact is, that the Clover had not only yielded so much more nitrogen in the removed crops, but it had also left the surface soil considerably richer in nitrogen. Thus, in October, 1873, after the removal of the Barley and the Clover, samples of soil were taken from 10 places on each of the two portions, and the nitrogen was determined in the samples from each of 4 of the individual holes separately, in the mixture of the 4, and in the mixture of the samples from the other 6 places. The determinations in the numerous separate samples consistently showed that, to the depth of 9 inches, the Clover-land soil which had yielded so much more nitrogen in the crops, was nevertheless determinably richer in nitrogen than the Barley-land soil, which had yielded so much less. This is sufficiently illustrated by the following figures, showing the mean percentage of nitrogen in the dry fine soil, of the Clover, and of the Barley-land, respectively :—

						Mean per cent. Nitrogen.
In Clover-land soil	...	...	...	...	...	0·1566
In Barley-land soil	...	...	...	...	...	0·1416

This was the case notwithstanding that all visible vegetable débris had first been removed from the samples. It was further found, that the above- and under-ground vegetable residue picked from the Clover-land samples, was much more in quantity, and contained much more nitrogen, than that from the Barley-land samples.

In 1874, and in 1875, barley only was sown over both portions. In 1876, barley was again sown over the whole of the land, with Clover as well on the portions where it had been grown in 1873 ; but the plant failed in the winter, and gave no crop in 1877. In 1877, Barley was again sown over the whole ; this time with Clover on half of the previously Clover portion, and on half of the previously only Barley portion. In the autumn of 1877, soil samples were again taken ; this time from 4 places on each of the differently cropped portions. The determinations of nitrogen in the surface soils consistently showed, as before, a higher percentage where Clover had grown than where only Barley had grown.

It is, of course, well known in agriculture, that the growth of Clover, which removes much more nitrogen than a cereal crop, increases the produce of a succeeding cereal as if nitrogenous manure had been applied. But what I wish specially to direct attention to is, the fact that a Leguminous crop accumulates a great deal more nitrogen over a given area than a Gramineous one under equal soil conditions.

YIELD OF NITROGEN IN THE CROPS OF A MANURED ROTATION.

Before considering the effects of direct nitrogenous manures on the different crops, it will be well to form some idea of the amount of nitrogen yielded in fairly good crops grown in rotation, with fairly liberal manuring. This point may conveniently be illustrated by the

results given in Table III. (below), which show the amounts of nitrogen in the crops grown in the experimental rotation at Rothamsted, for which a full manure, both mineral and nitrogenous, is applied for the Turnips commencing each course. The whole of the crops, roots and leaves in the case of the Turnips, and both corn and straw in that of the Cereals and the Beans, are removed from the land, and the figures show the average amounts of nitrogen in the crops over 8 courses in each case, that is over a period of 32 years in all.

TABLE III.

Yield of Nitrogen in Crops grown in four-course rotation, with artificial mineral and nitrogenous manures.
8 courses, 32 years, 1852-1883.

										Average yield of Nitrogen per acre per annum.
										lbs.
1.	Swedish Turnips..	..	..	..	..	..	..	..	..	80·6
2.	Barley	..	..	..	..	..	..	..	..	40·7
3.	{ Clover (2 courses)	..	..	..	..	..	..	..	..	167·0
	{ Beans (6 courses)	..	..	..	..	..	..	..	..	63·6
4.	Average Clover and Beans ..	..	..	..	..	..	..	..	..	89·5
	Wheat	..	..	..	..	..	..	..	..	43·7
Average of all crops										63·6

If we compare the amounts of nitrogen in these crops, for which nitrogenous as well as mineral manures were applied, with those obtained in a corresponding rotation but without nitrogenous manure, as shown in Table I. (p. 3), it is seen that every one of the crops, the Roots for which the manure was directly applied, the Cereals, and the Leguminous crops, all yield much more nitrogen than when no nitrogenous manure was applied. The amounts of nitrogen obtained in the Cereals are about the same as, or perhaps rather less than, in average good crops grown in ordinary farm practice. The amounts obtained in the Turnips are also perhaps rather less than in average good crops, and considerably less than in a good crop of Mangel-Wurzel. The amounts in the Beans are also less than in a good crop of Beans, grown on suitable Bean-land, but the amounts in the Clover are more than in the average of crops grown in ordinary rotation.

Taking the results as they stand, it is seen that, both the Roots and the Leguminous crops accumulate much more nitrogen than either of the Cereals grown in alternation with them. Lastly, whilst the average yield of nitrogen, per acre per annum, over 32 years was, without nitrogenous manure only 38·6 lbs. (see Table I.), it is, with nitrogenous manure, 63·6 lbs.; and compared with this latter amount, it may be mentioned that, in a similarly manured rotation, but with fallow instead of a leguminous crop in the third year, the annual yield of nitrogen was only 39·9 lbs.

PERCENTAGE OF NITROGEN, IN THE DRY SUBSTANCE OF
VARIOUS CROPS.

Not only is the yield of nitrogen per acre much less in the Cereal crops, but the percentage of nitrogen in the dry substance of the Gramineous produce is much less than in that of the Leguminous produce. This is illustrated in Table IV. (below), which shows the average percentage of nitrogen in the dry substance of various crops.

TABLE IV.

Average Percentage Nitrogen in the dry substance of various Crops.

									Corn or Roots.	Straw or Leaf.
									Per cent.	Per cent.
Wheat ..	..	..	..	..	..	..	..	..	2.12	0.54
Barley ..	..	..	..	..	..	..	..	..	1.96	0.47
Oats ..	..	..	..	..	..	..	..	..	2.33	0.60
Maize ..	..	..	..	..	..	..	..	..	1.93	
Peas ..	..	..	..	..	..	..	..	..	4.24	1.21
Beans ..	..	..	..	..	..	..	..	..	4.71	1.09
White Turnips	..	..	..	..	..	..	..	..	2.25	3.7
Yellow Turnips	..	..	..	..	..	..	..	..	2.22	
Swedish Turnips	..	..	..	..	..	..	..	..	2.27	4.0
Mangel Wurzel	..	..	..	..	..	..	..	..	1.76	2.9
Potatoes ..	..	..	..	..	..	..	..	..	1.00	
HAY.										
Meadow Hay ..	..	..	..	..	..	..	..	..	1.79	
Clover Hay ..	..	..	..	..	..	..	..	..	2.89	

Thus it is seen, that the corn of the Leguminous crops, Beans and Peas, contains more than twice as high a percentage of nitrogen in its dry substance as that of the Gramineous grains. The dry substance of the Leguminous straws, also contains about twice as high a percentage of nitrogen as that of the Cereal straws. Again, the dry substance of Clover-hay contains not far short of twice as much nitrogen as that of Meadow-hay. Lastly, the dry substance of the Roots contains about the same percentage of nitrogen as that of the Cereal grains, but only about half as much as that of the Leguminous corn. The leaves of the Root-crops are, however, high in nitrogen.

The general result is, then, that the *non*-Leguminous crops, especially those of the Gramineous family, are characterised, both by yielding much less nitrogen in their produce over a given area, and by containing a much lower percentage of nitrogen in their dry substance, than the Leguminous crops. Bearing these facts in mind, let us now turn to the consideration of the effects of direct nitrogenous manures on the various crops.

EFFECTS OF NITROGENOUS MANURES IN INCREASING THE
PRODUCE OF VARIOUS CROPS.

I need not remind you that, under the conditions in which the crops are grown in ordinary agriculture, nitrogenous manures have very marked effects in increasing the amounts of produce of Wheat, of Barley, of Turnips, of Mangels, and of Potatoes ;—that is, of the comparatively low-in-nitrogen *non*-Leguminous crops. For detailed evidence on the point, I may refer you to my former lectures relating to these various crops. But I may recall to mind the fact that—in the case of Wheat and Barley the increased produce consists characteristically of the non-nitrogenous substances starch and cellulose, in that of the Root-crops of the non-nitrogenous substance sugar, and in that of Potatoes of the non-nitrogenous substance starch.

Table V. (p. 10), illustrates very strikingly the influence of nitrogenous manures in increasing the production of the non-nitrogenous constituents of our crops.

The first column of figures shows, the estimated amounts of carbon, per acre per annum, in the total produce of Wheat and of Barley, in the roots of Sugar-Beet and Mangel-Wurzel, in the tubers of Potatoes, and in the total produce of Beans ; in each case when grown by a complex mineral manure without nitrogen, and also with the same mineral manures with nitrogenous manure in addition. The second column shows the estimated gain of carbon ; that is, the increased amount of it assimilated under the influence of the nitrogenous manures. The third column shows the estimated increased production of total carbohydrates, under the influence of the nitrogenous manures ; and the last column the estimated gain of carbohydrates for 1 of nitrogen in manure.

The mode of calculating the amounts of carbon and of carbohydrates is as follows. From the amount of dry substance in the crops, the amounts of mineral matter and of nitrogenous substance are deducted ; and the remainder represents the amount of carbohydrates. The amount of carbon in the nitrogenous substance is calculated ; and then that in the carbohydrate, on the assumption that, in the Wheat, Barley, and Beans, starch and cellulose are the main products ; in the Sugar-Beet and Mangel-Wurzel, cane-sugar, pectine, and cellulose ; and in the Potatoes, starch and cellulose. Such estimates can, obviously, only be approximations to the truth ; but, accepted as such, they are useful, as conveying some definite impression, of the influence of nitrogenous manures on carbon-assimilation, and on carbohydrate-formation.

As Table V. shows, the calculations are based on the average produce, by the different manures, of Wheat over 20 years, of Barley over 20 years, of Sugar-Beet over 3 years, of Mangel-Wurzel over 8 years, of Potatoes over 10 years, and of Beans over 8 years.

It is thus seen that, independently of the underground growth, the Wheat was estimated to assimilate 988 lbs. of carbon per acre per

annum, under the influence of a complex mineral manure alone; and that the amount was increased to 1,590 lbs. by the addition of 43 lbs. of nitrogen as ammonium-salts, to 2,222 lbs. by 86 lbs. of nitrogen as ammonium-salts, and to 2,500 lbs. by 86 lbs. nitrogen as sodium-nitrate. Accordingly, as shown in the second column, the increased assimilation of carbon was, by 43 lbs. of nitrogen as ammonium-salts 602 lbs., by 86 lbs. as ammonium-salts 1,234 lbs., and by 86 lbs. as sodium-nitrate 1,512 lbs.

TABLE V.

Estimates of the Yield and Gain of Carbon, and of the Gain of Carbohydrates, per acre per annum, in various Experimental Crops, grown at Rothamsted.

	Carbon.		Carbohydrates.	
	Actual.	Gain.	Gain.	For 1 Nitrogen in Manure.
WHEAT 20 years, 1852-1871.				
Mineral Manure	lbs: 988	lbs.	lbs.	lbs.
Mineral Manure and 43lbs. Nitrogen as Ammonia..	1590	602	1240	28·8
Mineral Manure and 86lbs. Nitrogen as Ammonia..	2222	1234	2550	29·7
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	2500	1512	3140	36·5
BARLEY 20 years, 1852-1871.				
Mineral Manure	1138			
Mineral Manure and 43lbs. Nitrogen as Ammonia..	2088	950	1992	46·3
SUGAR-BEET 3 years, 1871-1873.				
Mineral Manure	1123			
Mineral Manure and 86lbs. Nitrogen as Ammonia..	2600	1477	3188	37·1
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	3031	1908	4052	47·1
MANGEL WURZEL 8 years, 1876-1883.				
Mineral Manure	759			
Mineral Manure and 86lbs. Nitrogen as Ammonia..	1889	1130	2376	27·6
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	2129	1370	2771	32·2
POTATOES 10 years, 1876-1885.				
Mineral Manure	1021			
Mineral Manure and 86lbs. Nitrogen as Ammonia..	1783	762	1507	17·5
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	1752	731	1416	16·5
BEANS 8 years, 1862 and 1864-1870.				
Mineral Manure	726			
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	992	266	474	5·5

Reckoned in the same way, the increased assimilation of carbon in the Barley was, for 43 lbs. nitrogen as ammonium-salts, 950 lbs. per acre; that is one-and-a-half time as much as by the same application in the case of wheat.

In the Sugar-Beet (the roots only), the increased assimilation of carbon was 1,477 lbs. per acre by the application of 86 lbs. nitrogen as

ammonium-salts, and 1,908 lbs. by 86 lbs. nitrogen as sodium-nitrate. There is, therefore, considerably more increased assimilation of carbon in the produce of Sugar-Beet than in that of Wheat by the same applications of nitrogenous manure.

In Mangel-Wurzel roots the increased assimilation of carbon was 1,130 lbs. by 86 lbs. of nitrogen as ammonium-salts, and 1,370 lbs. by 86 lbs. as nitrate; that is less than in the removed crops (corn and straw) of Wheat, and considerably less than in the removed crops (the roots) of Sugar-Beet.

In the case of the Potatoes, reckoned on the increased production of tubers only (the tops being left on the land), the increased yield of carbon by 86 lbs. of nitrogen as ammonium-salts is 762 lbs. per acre, and by 86 lbs. as sodium-nitrate 731 lbs. That is to say, there is considerably less increased production of starch in Potatoes, than of sugar in Sugar-Beet, or Mangel-Wurzel, by the same applications of nitrogenous manure.

Lastly, in the Leguminous crop, Beans, with its high yield of nitrogen per acre, and the high percentage of nitrogen in its dry substance, the increased assimilation of carbon under the influence of nitrogenous manure was comparatively quite insignificant. Thus, there was, by the application of 86 lbs. of nitrogen as sodium-nitrate, an increased assimilation of carbon of only 266 lbs. per acre; or little more than one-sixth as much as in Wheat, and little more than one-eighth as much as in Sugar-Beet, by the same application.

Turning to the figures in the third column, it is seen that the estimated increased production of the non-nitrogenous carbohydrates, by the use of nitrogenous manures, was very great.

Thus, by the use of 43 lbs. of nitrogen as ammonium-salts, there is an estimated increase of 1,240 lbs. of carbohydrates in Wheat, and of 1,992 lbs. in Barley. By the application of 86 lbs. of nitrogen as ammonium-salts, there was an increased formation of carbohydrates of 2,550 lbs. in Wheat, of 3,188 lbs. in Sugar-Beet, of 2,376 lbs. in Mangel-Wurzel, and of only 1,507 lbs. in Potatoes; and when 86 lbs. were applied as sodium-nitrate, there was an increased production of 3,140 lbs. in Wheat, of 4,052 lbs. in Sugar-Beet, of 2,771 lbs. in Mangel-Wurzel, and of only 1,416 lbs. in Potatoes. Whilst, compared with these amounts, there was, by the same application, an increase of only 474 lbs. of carbohydrates in Beans.

The last column shows the estimated increased amounts of carbohydrates produced for 1 lb. of nitrogen in manure, in the different cases. Thus, when 43 lbs. of nitrogen were applied as ammonium-salts, 1 lb. of nitrogen in manure gave an increased production of 28.8 lbs. of carbohydrates in wheat, and of 46.3 lbs. in Barley; when 86 lbs. nitrogen were applied as ammonium-salts, 1 lb. gave an increase of 29.7 lbs. carbohydrates in Wheat, 37.1 lbs. in Sugar-Beet, 27.6 lbs. in Mangel-Wurzel, and 17.5 lbs. in Potatoes. Again, when 86 lbs. were applied as sodium-nitrate, 1 lb. gave an increase of 36.5 lbs. carbohydrates in Wheat, 47.1 lbs. in Sugar-Beet, 32.2 lbs. in Mangel-Wurzel, 16.5 lbs. in Potatoes, and only 5.5 lbs. in the Leguminous crop—Beans.

It is natural to ask—what is the explanation of the apparently anomalous result, that the crops which are characterised by containing comparatively little nitrogen, and by yielding large amounts of non-nitrogenous products—starch, sugar, and cellulose—are especially benefited by the application of nitrogenous manures; and that, under their influence, they yield greatly increased amounts of those non-nitrogenous bodies?

It is, perhaps, little more than stating the facts in another way to say, as is the case, that the luxuriance, or activity of growth, of all these crops, is very greatly enhanced by nitrogenous manures; and that, since their special products are these non-nitrogenous substances, the natural result of the increased luxuriance is to increase the formation of the bodies which are their essential or characteristic products.

A further possible explanation of the curious results has, however, been suggested.*

Thus, on purely chemical and physiological grounds, and, so far as would appear, without any special reference to the fact that, in the case of our chief starch and sugar yielding crops, the production of those substances is greatly enhanced by the use of nitrogenous manures, it has been suggested that the substance first formed in the chlorophyll-corpuscle, from carbon-dioxide and water, is not starch, but a substance possibly allied to formic aldehyde (CH_2O), which goes to construct proteid, by combining with the nitrogen and sulphur absorbed in the form of salts from the soil, or with the nitrogenous residues of previous decompositions of proteid. It is supposed, however, that starch may, nevertheless, be the first *visible* product of the constructive metabolism; since, unless protoplasm were being formed, no starch could be produced.

This view is partly founded on the consideration of the analogy that would then be established, between the formation of starch and that of the carbohydrate—cellulose; which is by some experimenters supposed to be derived directly from protoplasm.

It is true, that such a supposition is at any rate not inconsistent with the conditions which we have seen to be favourable for the increased production of starch and sugar in agricultural plants. At the same time, it is admittedly at present little more than hypothesis. It would, indeed, require more evidence than is at present available, to establish such a conclusion; whilst there are considerations which would lead us to hesitate to adopt the view in question, without clear experimental proof.

Thus, it seems difficult to suppose, that the undoubted connection in some striking cases, between the amount of nitrogen taken up by the plant, and the amount of starch or sugar formed, is to be explained by an assumption which implies that a chief office of the nitrogenous bodies of plants is to serve as intermediate only, in the transformations

* See Vines' Lectures on the "Physiology of Plants," p. 140, *et seq.*

necessary for the formation of the non-nitrogenous substances. The view does not, however, assume that nitrogen is eliminated from the plant in the process, and so lost.

Then, again, plants such as many of the Leguminosæ, which are characterised by assimilating relatively very large amounts of nitrogen over a given area of land, and by the formation of very large amounts of proteid in proportion to plant surface, produce relatively small amounts of the carbohydrates.

Nor is it irrelevant to refer to the fact that, from theoretical considerations, it was for many years assumed, especially in Germany, in opposition to the teachings of our own numerous direct experiments, that in the animal body the non-nitrogenous substance—fat—was mostly, if not always, produced by the degradation of proteid; the nitrogenous bye-products being for the most part, if not entirely, eliminated from the body as waste matter. It is, however, now indubitably established, at any rate in the cases of the *herbivora* which produce the most fat, that that substance is derived largely, if not exclusively, from the non-nitrogenous constituents of the food—the carbohydrates.

In the case of the supposed transformation in plants, the same prodigal expenditure of the nitrogenous bodies in the formation of the non-nitrogenous is, however, as has been said, not involved.

EFFECTS OF NITROGENOUS MANURES ON LEGUMINOUS CROPS.

Such are the very marked effects of nitrogenous manures in increasing the amounts of produce, and especially in increasing the production of non-nitrogenous constituents, when applied to our *non-Leguminous*, and comparatively low in nitrogen, crops. I have now to illustrate the influence of nitrogenous manures on various Leguminous crops, which, on the other hand, are characterised by containing a high percentage of nitrogen in their dry substance, and by assimilating a large amount of nitrogen from some source over a given area of land. It will be seen that the results to which I have to direct attention will bring to view some very remarkable failures, but also some not less signal and significant successes.

My first illustrations relate to experiments with Beans, grown for many years in succession on the same land—without manure, with a purely mineral manure (consisting of superphosphate of lime, and salts of potash, soda, and magnesia), also with the same mineral manure, and nitrogenous manure in addition, supplied either as ammonium-salts, or as sodium-nitrate. The results are recorded in Table VI. (p. 14).

It is seen that the record relates to a period of 32 years of continued or interrupted experiment with Beans, from 1847 to 1878 inclusive.

The first three columns show the produce of the corn, the second three that of the straw, and the third three that of the total produce, corn and straw together; each under three conditions as to manuring.

TABLE VI.

BEANS.

Grown year after year on the same land, Geescroft Field, Rothamsted.
Results, without Manure, with Mineral Manure, and with Mineral and Nitrogenous Manure.

Produce per acre, each year, in lbs.

Years.	Total Corn.			Total Straw.			Total Produce (Corn and Straw).		
	Unma- nured.	Mixed Mineral Manure (includ- ing Potash).	Mixed Mineral Manure and Ni- trogen. (1)	Unma- nured.	Mixed Mineral Manure (includ- ing Potash).	Mixed Mineral Manure and Ni- trogen. (1)	Unma- nured.	Mixed Mineral Manure (includ- ing Potash).	Mixed Mineral Manure and Ni- trogen. (1)
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1847	1611	1697	1746	2125	1959	2185	3736	3656	3931
1848	1390	1831	2048	1269	1532	1730	2659	3363	3778
1849	2173	(2390)	2250	1641	(2)	1743	3814	(2)	3993
1850	1071	1432	1679	1070	1312	1441	2141	2744	3120
1851	2074	3315	3554	1920	3279	3568	3994	6594	7122
1852	697	855	1007	820	1286	1541	1517	2141	2548
1853	260	462	555	489	802	992	749	1264	1547
1854	365	1423	1266	394	1272	1133	759	2695	2399
1855	987	956	889	770	828	788	1757	1784	1677
1856	755	1627	1568	808	1914	1900	1563	3541	3468
1857	732	660	648	676	644	636	1408	1304	1284
1858	126	640	612	654	1392	1300	780	2032	1912
1859	142	352	401	196	416	498	338	768	899
1860	Fallow								
1861 (3)	(2156)	(2434)	(2509)	(3869)	(4596)	(4742)	(6025)	(7030)	(7251)
1862	513	1014	1479	930	2256	3064	1443	3270	4543
1863	Fallow								
1864	133	1672	1837	960	2568	2468	1093	4240	4305
1865	261	514	1296	704	1080	2180	965	1594	3476
1866	142	316	914	317	628	1190	459	944	2104
1867	49	381	604	280	1252	1360	329	1633	1964
1868	48	384	478	533	930	1203	581	1314	1681
1869	106	926	1303	338	1394	1607	444	2320	2910
1870	458	450	615	516	483	533	974	933	1148
1871	Crop destroyed	by severe	winter						
1872	Fallow								
1873	Fallow								
1874	1259	1899	2087	944	1328	1568	2203	3227	3655
1875	1193	882	1114	1674	1988	2576	2867	2870	3690
1876	Fallow								
1877	674	1974	1685	722	1809	1533	1396	3783	3218
1878	148	949	1108	301	1216	1496	449	2165	2604

Average per acre per annum, over each period of 8 years, and the total period of 32 years.

8 yrs., 1847-1854	1205	1573 (4)	1763	1216	1635 (4)	1792	2421	3208 (4)	3555
8 yrs., 1855-1862	676	960	1013	988	1506	1616	1664	2466	2629
8 yrs., 1863-1870	150	580	881	456	1042	1317	606	1622	2198
8 yrs., 1871-1878	409	713	749	455	793	897	864	1506	1646
32 yrs., 1847-1878	610	937 (5)	1102	779	1231 (5)	1405	1389	2168 (5)	2507

Average per acre per annum, over the years of crop only, each period.

1st 8 yrs., 8 crops	1205	1573 (6)	1763	1216	1635 (6)	1792	2421	3208 (6)	3555
2nd 8 yrs., 7 crops	773	1097	1158	1129	1721	1847	1902	2318	3005
3rd 8 yrs., 7 crops	171	663	1007	521	1191	1506	692	1854	2513
4th 8 yrs., 4 crops	819	1426	1499	910	1585	1793	1729	3011	3292
32 yrs., 26 crops	751	1162 (7)	1356	958	1526 (7)	1730	1709	2688 (7)	3086

(1) 5 years, 1847-1851, 46 lbs. Nitrogen as Ammonium Salts; 11 years, 1862, 1864-1870, 1875, 1876, and 1878, 86 lbs. Nitrogen as Sodium Nitrate. (2) Accidentally not weighed. (3) Wheat. (4) 7 years, excluding 1849. (5) 31 years, excluding 1849. (6) 7 crops, excluding 1849. (7) 25 crops, excluding 1849.

It should be further explained that, in the first 5 years, the nitrogen applied to the third plot was in the form of ammonium-salts. The effects were, however, so small and irregular, that the application of nitrogenous manure was then suspended for some years ; indeed for 10 years, when, it having been observed that nitrates were more beneficial to Leguminosæ than ammonium-salts, sodium-nitrate was applied instead ; in amount supplying 86 lbs. nitrogen per acre per annum, or nearly twice as much as had been given as ammonium-salts in the earlier years. This application of the nitrate commenced in 1862 ; and with some breaks, owing to severe or wet winters, which prevented the seed being sown, or destroyed the plant, it was continued up to 1878, when the experiments were finally abandoned.

Referring to the results, a glance at the Table shows that, independently of fluctuations obviously due to season, there were frequent entire failures, which were also more or less due to season, but which were also dependent partly on the conditions induced in the land by the continuous cropping with this plant ; which, as is the case with most Leguminosæ, is very susceptible to parasitic attacks of various kinds, when the conditions of growth are not normal and favourable. Indeed, it is seen that, even when there was not absolute failure, there was a general tendency to decline in yield, and then to recover again, more or less, after a break. This was somewhat marked after a year of Fallow in 1860, and the growth of Wheat in 1861 ; after which there was, in 1862, fair produce, especially on the third plot, where the nitrate was now applied. The land was again Fallow in 1863, and this was again followed by improved growth ; after which there was declining produce for a number of years to 1870 inclusive, and again recovery in 1874, after 3 years of Fallow. This general view of the results is of interest, as fixing attention on the great tendency to failure of this Leguminous crop, when grown year after year on the same land.

Turning to the effects of the different manures, it will suffice to direct attention to the last three columns of the Table, which record the amounts of total produce, that is corn and straw together, under each of the three conditions as to manuring.

Disregarding the results of the first year, when the unmanured plot gave relatively high produce, it is seen that, although there are irregularities, there is generally, whether the crops are large or small, a considerable increase of produce by the use of the mineral manure containing potash, but there is comparatively little further increase by the addition of nitrogenous to the mineral manure. Thus, as shown in the bottom division but one of the Table, the average annual total produce, over the 32 years (which however included 7 without any Bean crop) was—without manure, 1,389 lbs., with the mineral manure alone 2,168 lbs., and with the mineral and nitrogenous manure together 2,507 lbs. That is to say, whilst the mineral manure without nitrogen gave an average annual increase of 779 lbs., the addition to it of nitrogenous manure only further raised the produce by 339 lbs.

Or if, instead of taking the average of the 32 years, we take it only over the 26 years in which there was any Bean crop, the average total produce was—without manure 1,709 lbs., with purely mineral manure 2,688 lbs., and with the mineral and nitrogenous manure together, 3,086 lbs. ; that is, there was an annual average increase of 979 lbs. by the mineral manure containing potash, and of only 398 lbs. more by the addition of nitrogenous manure.

The details further show that—without manure, the total produce of two of the last 8 years was only exceeded three or four times during the whole period, namely during the first five years ;—with mineral manure alone, the total produce of 2 of the last 8 years was only exceeded four or five times ;—and with the mineral and nitrogenous manure together, the total produce of 2 of the last 8 years was only exceeded six times. Indeed, on both of the manured plots, the average total produce over the last 4 years of actual crop, was nearly as much as the average of the first 8 years of crop. Thus, with the purely mineral manure, the average total produce of the first 8 years was 3,208 lbs., and over the last 4 years of crop it was 3,011 lbs., and with the mineral and nitrogenous manure, it was over the first 8 years 3,555 lbs., and over the last 4 years of crop 3,292 lbs. It will be seen further on, that the average annual yield of nitrogen was also nearly as great over the last 4 years, as over the first 8 years, of crop.

It may be observed that nitrogen supplied as ammonium-salts to the highly nitrogenous Leguminous crops, seldom gives any increase, and is sometimes injurious, in the year of application ; though some benefit may afterwards result from the residue after the ammonia has been converted into nitric acid. Even nitrates, however, directly applied as manure, are very uncertain in their action, and at any rate yield very much less increase of produce with the highly nitrogenous Leguminosæ, than with the Gramineæ, and crops of other families, yielding produce of low percentage of nitrogen in its dry substance, and appropriating comparatively little nitrogen over a given area of land.

To this point I shall have to refer in some detail further on, but in the meantime it is to be specially noted, that whilst the Cereal crops may be successfully grown for many years in succession on the same land, provided only that mineral and nitrogenous manures are liberally supplied, the Leguminous crop—Beans, gradually fails when so grown ; and although characteristically benefited by mineral manures containing potash, neither these alone, nor a mixture of mineral and nitrogenous manure, has sufficed to maintain even fair growth for a number of years in succession.

The result is, however, not entirely due to deficiency in the supply of constituents within the soil, but is also in a considerable degree dependent on the fact that, by the continuous growth of the crop, with its special habit, and range of roots, the surface soil acquires a close and unfavourable condition, and a somewhat impervious pan is formed below. The improved result in the later years, with the inter-

vention of Fallow, further illustrates the fact that the previous failures were not wholly due to exhaustion.

The next Table, VII. (below), shows the amounts of nitrogen in the Bean crops, the produce of which we have been considering.

TABLE VII.

BEANS.

Grown year after year on the same land, with different Manures, in Geescroft Field, Rothamsted.

Yield of Nitrogen, lbs. Average per acre, per annum, 8-year periods.

Periods.	In Corn.			In Straw.			In Total Produce (Corn and Straw).		
	Unma- nured.	Mixed Mineral Manure (includ- ing Potash).	Mixed Mineral Manure and Ni- trogen. (1)	Unma- nured.	Mixed Mineral Manure (includ- ing Potash).	Mixed Mineral Manure and Ni- trogen. (1)	Unma- nured.	Mixed Mineral Manure (includ- ing Potash).	Mixed Mineral Manure and Ni- trogen. (1)
Average per acre per annum, over each period of 8 years, and the total period of 32 years.									
8 yrs., 1847-1854	39.0	48.4 (2)	54.5	9.4	11.8 (2)	14.5	48.4	60.2 (2)	69.0
8 yrs., 1855-1862	18.3	24.4	26.5	7.0	9.9	10.3	25.3	34.3	36.8
8 yrs., 1863-1870	5.1	16.0	26.4	4.1	7.5	8.7	9.2	23.5	35.1
8 yrs., 1871-1878	13.0	21.2	22.3	3.4	5.5	6.4	16.4	26.7	28.7
32 yrs., 1847-1878	18.9	26.8 (3)	32.4	5.9	8.6 (3)	10.0	24.8	35.4 (3)	42.4

Average per acre per annum, over the years of crop only, each period.

1st 8 yrs., 8 crops	39.0	48.4 (4)	54.5	9.4	11.8 (4)	14.5	48.4	60.2 (4)	69.0
2nd 8 yrs., 7 crops	20.9	27.9	30.3	8.0	11.3	11.8	28.9	39.2	42.1
3rd 8 yrs., 7 crops	5.8	18.3	30.1	4.6	8.5	9.9	10.4	26.8	40.0
4th 8 yrs., 4 crops	26.0	42.4	44.5	6.7	10.9	12.9	32.7	53.3	57.4
32 yrs., 1847-1878 26 crops	23.2	33.3 (5)	39.9	7.3	10.6 (5)	12.3	30.5	43.9 (5)	52.2

(1) 5 years, 1847-1851, 46 lbs. Nitrogen as Ammonium Salts; 11 years, 1862, 1864-1870, 1875, 1876, and 1878, 86 lbs. Nitrogen as Sodium Nitrate. (2) 7 years, excluding 1849. (3) 31 years, excluding 1849. (4) 7 crops, excluding 1849. (5) 25 crops, excluding 1849.

GENERAL NOTE.—In the second 8 years, the land was fallow in 1860, and wheat was grown in 1861; in the third 8 years, 1863 was fallow; and in the fourth 8 years, the crop failed in 1871, and the land was left fallow in 1872, 1873, and 1876.

The Table is on the same plan as that relating to the produce, but instead of results for every year of the 32, there are now given only averages, in the upper division for the four 8 yearly periods, and for the total period of 32 years; and in the lower division for the years of crop only, within each period. As in Table VI., the first three columns give for each of the three conditions as to manuring, the results for the corn, the second three for the straw, and the last three for the total produce, corn and straw together. It will suffice to direct attention to these last results.

Referring to the figures in the upper division, it may be observed that, notwithstanding there were 6 blank years, and 1 year of wheat, out of the 32, and notwithstanding that the produce declined much, and gave on the whole much less than the average obtained under ordinary agricultural conditions, yet the average yield of nitrogen in the

crops grown without any supply of it was much more than in either of the Cereals, the Root-crops, or Potatoes, grown under similar conditions.

Thus, as the bottom line of the upper division shows, there was an average, over the 32 years, of 24·8 lbs. of nitrogen, per acre per annum, in the crops without any manure, but of 35·4 lbs. with the mineral manure without nitrogen; whilst the amount was raised to only 42·4 lbs. by the addition of nitrogenous manure. Over the first 8 years, however, the yield was very much higher, being for the three plots, respectively, 48·4, 60·2, and 69·0 lbs. Over the second period of 8 years the average was not far from that of the whole 32 years; but over the third and fourth periods it was much less.

As in the case of the total produce itself, so also in that of the nitrogen in the total produce, if we take the averages of the years of crop only, as given in the bottom division of the Table, we have a much higher average yield per annum over the 4 years of crop of the last 8 years, than over the years of crop of either the second or the third period of 8 years. Indeed, on the two manured plots, there is an average annual yield of nitrogen per acre, over the 4 years of crop during the last 8 years, not far short of the average of the first 8 years. Thus, with the purely mineral manure, there is an average annual yield of nitrogen over the first 8 years of 60·2 lbs., and over the 4 years of crop of the last 8 years, of 53·3 lbs.; and with the mineral and nitrogenous manure together, over the first 8 years, of 69·0 lbs., and over the 4 years of crop of the last 8 years, of 57·4 lbs.

That is, with the intervention of Fallow, we have, though not good agricultural crops, yet really large yields of nitrogen, compared with those obtained in many of the preceding years; and very large yields without any supply by manure, compared with those obtained under the same conditions with any of the *non*-Leguminous crops. It would appear probable, therefore, that if a suitable mechanical condition of the land could have been maintained, fair crops, and large yields of nitrogen, would also have been maintained.

Upon the whole, then, although the crop practically failed, when it was attempted to grow it year after year on the same land, it nevertheless accumulated, in its above-ground produce, much more nitrogen over a given area than the crops of the other families, but was little benefited by an artificial supply of nitrogen.

I have now to record a still greater failure, with another crop of the Leguminous family—namely, *Trifolium pratense*, or Red Clover. The results are summarised in Table VIII. (p. 19).

The Table is headed Red Clover sown frequently on the same land; and the first column shows that the period of experiment was 29 years, from 1849 to 1877 inclusive. But the details show that, although Clover was sown 15 times, in only 7 of the 29 years was any Clover-crop obtained; whilst about one-fifth of the produce of the whole series of years was yielded in the first year, 1849. It is, indeed, well known in agriculture, that Clover will not grow, under ordinary conditions, more

frequently than once in a certain number of years, which varies according to soil and other circumstances, but is seldom so few as four, and frequently as much as 8 years.

TABLE VIII.
RED CLOVER.

Sown frequently on the same land, in Hoosfield, Rothamsted.

Total Produce, per acre per annum; Clover as Hay, other Crops Corn and Straw together.

Year.	Description of Crop.	SERIES 1. Mineral Manure alone.	SERIES 2. Mineral and Nitrogenous Manures.
		lbs.	lbs.
1849	Clover	10214	10326
1850	Wheat	(6261)	(6345)
1851	Clover	2309	2368
1852	Clover	5895	4914
1853	Clover	No crop.	No crop.
1854	Fallow		
1855	Clover	1281	2606
1856	Fallow		
1857	Fallow		
1858	Barley	(6598)	(7578)
1859	Clover	2752	3087
1860	Clover	No crop.	No crop.
1861	Fallow		
1862	Barley	(5745)	(6730)
1863	Fallow		
1864	Clover	No crop.	No crop.
1865	Clover	2467	4500
1866	S. 1 Clover, S. 2 Barley ..	No crop.	(2974)
1867	Fallow		
1868	Clover	No crop.	No crop.
1869	Clover	No crop.	No crop.
1870	Barley	(3328)	(3312)
1871	Clover	No crop.	4085
1872	Fallow		
1873	Fallow		
1874	Clover	No crop.	Fallow.
1875	Clover	4277	Fallow.
1876	Fallow		
1877	Barley	(1864)	(1864)

SUMMARY. PRODUCE.

29 years, 1849-1877..	{ Total.. .. .	52991	60689
	{ Average	1827	2093
Years of Crop only..	{ Average	4416	4668
Years of Clover only (7) ..	{ Total.. .. .	29195	31886
	{ Average	4171	4555

SUMMARY. NITROGEN (Estimated).

29 years, 1849-1877..	{ Total.. .. .	929.4	1043.1
	{ Average	32.0	36.0
Years of Crop only..	{ Average	77.5	80.2
Years of Clover only (7) ..	{ Total.. .. .	700.7	765.3
	{ Average	100.1	109.3

The second column shows that, owing to the failure of the Clover, sometimes a cereal crop, Wheat or Barley, was sown; but more frequently the land was left Fallow. The produce of Wheat, or of Barley, is given between brackets.

The amounts of produce entered in the column headed Series 1, are, in each case, the means of those on 3 plots, each of which occasionally received a mineral manure containing potash; and the results given in the column, Series 2, are also the means of 3 plots, each with the mineral, and nitrogenous manures in addition, occasionally applied.

It is seen that very large crops of Clover were obtained in the first year, 1849; less than one-quarter as much in the third year, 1851; and in the fourth year about half as much as in the first. There was then no more Clover until the seventh year, when there was very little. More or less was afterwards obtained in the eleventh, seventeenth, twenty-third (on one plot), and lastly (on one plot) in the twenty-seventh year; but, in no case excepting in the fourth year, was the amount of produce half as much as in the first year.

Comparing the results without, and with, the nitrogenous manure, it is shown, in the summary at the bottom of the Table, that the average annual total produce, of Clover-hay, or of other crops, was, reckoned over the 29 years, 1827 lbs. without, and 2093 lbs. with, the nitrogenous manure; and, reckoned in the same way, the average annual yield of nitrogen was, without nitrogenous manure 32 lbs., and with it 36.0 lbs. Reckoned, however, over the years of crop only, the yield of nitrogen in the Clover and other crops, was, 77.5 lbs. per acre per annum without, and 80.2 lbs. with, the nitrogenous manuring. Or, reckoning the nitrogen in the Clover alone, and only over the years when it gave any crop, the average annual yield of it over those 7 years was, without nitrogenous manure 100.1 lbs., and with it, 109.3 lbs. There was, therefore, comparatively little increase, either in the produce, or in the yield of nitrogen, by the use of nitrogenous manures.

To conclude in regard to these experiments:—The attempt to grow Clover year after year on ordinary arable land, by means of such mineral manures as increase the luxuriance of growth when there is a fair plant, or even by the addition to these of nitrogenous manures, has entirely failed. In view of this failure to grow the crop continuously on ordinary arable land, the next results to which I have to call attention are of much interest and significance.

GROWTH OF RED CLOVER, YEAR AFTER YEAR, ON RICH GARDEN SOIL.

In 1854, after it seemed clear that the plant would not continue to grow on the arable land, Clover was sown in a garden, only a few hundred yards distant from the experimental field, on soil which had been under ordinary kitchen-garden cultivation for probably two or three centuries. It is remarkable that, under these conditions, the crop has grown luxuriantly almost every year since; this year, 1889, being the 36th season of the continuous growth. Further particulars

will be given on the point presently, but it may here be premised that, at the commencement, the percentage of nitrogen in the surface soil of the garden was at least four times as high as in that of the arable soil in the field, and it would doubtless be richer in all other matters also. Indeed, it is probable that the subsoil of the garden, below the first 9 inches of depth, would be as rich, and perhaps richer than the surface soil of the field. Table IX. (below), gives the results for 35 of the 36 years of experiment with Clover on the rich garden soil.

TABLE IX.
RED CLOVER.

Grown year after year on Rich Garden-soil, The Garden, Rothamsted.
Hay, Dry Matter, Mineral Matter, and Nitrogen, per acre, per annum.

Years.	Number of Cuttings.	As Hay.	Dry Matter.	Mineral Matter.	Estimated Nitrogen.	Dates of Sowing Seed.
		lbs.	lbs.	lbs.	lbs.	
1854	2	5,191	4,326	435'0	124'6	1854, March 29.
1855	3	18,113	15,094	1560'0	434'7	
1856	2	11,027	9,190	1115'5	264'6	
1857	3	14,855	12,379	1384'0	356'5	
1858	2	7,608	6,340	792'0	182'6	
1859	2	6,227	5,189	686'5	149'4	1860, May.
1860	1	8,679	7,233	806'0	208'3	
1861	2	13,353	11,128	1285'0	320'5	
1862	2	10,042	8,368	990'5	241'0	
1863	2	11,798	9,832	971'0	283'2	
1864	2	5,500	4,583	446'0	132'0	1865, April 22.
1865	1	2,044	1,704	189'5	49'1	
1866	2	10,456	8,713	907'5	250'9	
1867	2	6,748	5,624	573'0	162'0	
1868	1	991	826	106'0	23'8	
1869	2	4,183	3,486	387'0	100'4	1868, April 29.
1870	1	1,741	1,451	148'0	41'8	
1871	1	4,513	3,761	458'0	108'3	
1872	2	10,142	8,452	898'5	243'4	
1873	2	9,287	7,740	772'0	222'9	
1874	3	5,899	4,916	539'5	141'6	1874, May 4, and July 7. 1875, July 13, and Sept. 22. 1876, Sept. 1 (died in winter). 1877, May.
1875	2	2,731	2,276	229'5	65'5	
1876	2	3,517	2,931	278'5	84'4	
1877	1	3,533	2,944	325'5	84'8	
1878	3	13,416	11,180	1335'5	322'0	
1879	1	2,738	2,282	427'5	65'7	1879, May 21. 1880, April 17. 1881, April 29 (mended). 1882, April 16 (mended). 1883, May 17.
1880	2	5,742	4,785	643'0	137'8	
1881	2	4,262	3,552	330'0	102'3	
1882	3	6,433	5,361	641'0	154'4	
1883	1	2,716	2,264	314'5	65'2	
1884	3	9,990	8,325	862'5	239'8	1886, April 14. 1887, April 21 (mended). 1888, April 13 (mended June 12).
1885	3	6,511	5,426	615'0	156'3	
1886	1	2,702	2,252	313'0	64'8	
1887	2	3,287	2,739	264'0	78'9	
1888	1	1,841	1,535	210'5	44'2	

SUMMARY. Averages.

10 years, 1854-'63	10,689	8,908	1002'5	256'5
10 years, 1864-'73	5,561	4,634	488'6	133'4
10 years, 1874-'83	5,099	4,249	506'5	122'4
5 years, 1884-'88	4,866	4,055	453'0	116'8
35 years, 1854-'88	6,795	5,663	635'4	163'1

The first column after the dates, shows the number of cuttings each year, the second the amounts of produce per acre, reckoned in the condition of dryness as hay, the third the amount of dry substance, the fourth that of the mineral matter, and the last the estimated amounts of nitrogen per acre in the crops. At the bottom of the Table are given the average annual results over periods of 10, 10, 10, 5, and 35 years. I shall confine attention to the amounts of produce reckoned as hay, and to the estimated amounts of nitrogen in the produce.

It should be stated that, as the garden-clover plot is only a few yards square, calculations of produce per acre can only give approximations to the truth; but it is believed that they can be thoroughly relied upon so far as their general indications are concerned. It may be added that five times during the whole period, gypsum has been applied to one-third, and a mineral manure containing potash, but no nitrogen, to another third of this plot.

Casting the eye down the column of produce as hay, it is seen at a glance that, excepting a few occasional years of very high produce during the later periods, the amount of crop is very much greater during the first, than during either of the subsequent periods of 10 or 5 years. In fact, as is seen at the foot of the Table, there was an average annual produce equal to 10,689 lbs. of hay, over the first period of 10 years, but of only 5,561 lbs. over the second, and 5,099 lbs. over the third, and of only 4,866 lbs. over the last 5 years.

Now, even these latter amounts correspond to what would be considered fair, though not large crops, when Clover is grown in an ordinary course of rotation, once only in 4, or in 8 years, or more; so that the produce in the earlier years on this rich garden-soil, was very unusually large. Indeed, the average annual produce over the whole period of 35 years, namely 6,795 lbs.—more than 3 tons of hay—would be a very good yield for the crop grown only occasionally in the ordinary course of agriculture.

But it is when we look at the figures in the last column of the Table, which show the estimated amounts of nitrogen in the crops, that the importance and significance of these results obtained on rich garden-soil, are fully recognised; and this is especially the case when they are compared with those obtained on ordinary arable land.

Thus, whilst the amount of nitrogen in average crops of Wheat, Barley, or Oats, will be from 40 to 50 lbs. per acre, of Beans about 100 lbs., of Meadow Hay about 50 lbs., and Clover Hay grown occasionally in rotation little more than 100 lbs.;—here, on this rich garden-soil, the produce of Clover has, in one year contained more than 400 lbs. of nitrogen, in three years more than 300 lbs., in several more than 200 lbs., and in only eleven years of the 35 less than 100 lbs.

In fact, as the figures at the bottom of the Table show, the estimated average annual yield of nitrogen in the above-ground growth was—over the first 10 years 256 lbs., over the second 10 years 133 lbs., over the third 10 years 122 lbs., over the last 5 years 117 lbs., and over the whole period of 35 years 163 lbs.; whilst, as the details show, the

yield in the 31st year (1884) was about 240 lbs., and in the 32nd year 156 lbs. of nitrogen.

Further, the average over the third 10 years of the continuous growth (122 lbs.), was about as much as in a fair average crop grown occasionally under the ordinary conditions of agriculture.

There would seem, then, to be clearly indicated, a soil source of failure on the arable-land, and a soil source of success on the garden-soil.

The results given in Table X. (below) will throw some further light on this point. It shows the percentage of nitrogen in the first 9 inches of depth of the garden-soil, in 1857 and in 1879, between which periods the growth of 21 years had been removed.

It also shows the estimated amounts of nitrogen per acre in the surface soil at the two periods, and the reduction in the amount during the 21 years.

TABLE X.

RED CLOVER.

Grown on Rich Garden Soil.

Nitrogen, per cent. and per acre, in the fine soil, dried at 100° C.
(First 9 inches of depth).

	1857.	1879.	Difference.
	Per cent. 0.5095	Per cent. 0.3634	Per cent. 0.1461
	lbs. 9,528	lbs. 6,796	lbs. 2,732
Per acre Total ..			130
Per acre per annum (21 years)			

It may be mentioned, that the percentage of nitrogen given for the sample collected in October, 1857, is the mean of duplicate or more determinations, made in 1857, in 1866, and again in 1880; and it is almost identical with the results obtained at the latest of these dates.

The first point to notice is, that the first 9 inches of depth of this rich garden-soil contained more than half a per cent. of nitrogen; that is, nearly four times as much as the average of the Rothamsted arable soils, and nearly five times as much as the exhausted arable Clover-land soil where the crop failed. It is, of course, true, that the garden-soil would be correspondingly rich in all other constituents; but some portions of the arable soil where the Clover failed, had received much more of mineral constituents by manure than had been removed in the crops.

The result given for 1879 is the mean of determinations made on three separate samples, for which the determinations agreed very well. The results can leave no doubt that there had been a great reduction in the stock of nitrogen in the surface-soil since 1857. The reduction amounts to nearly 29 per cent. of the whole in the 21 years; and, reckoned per acre, as shown in the bottom line of the Table, it corresponded to a loss of 2,732 lbs. during the 21 years; and, although, as

has been seen, fairly average, and even good crops, were still grown, it is obvious that coincidently with this great reduction in the stock of nitrogen in the surface-soil, there has been a very marked reduction in the Clover-growing capability of the soil.

On this point it may be mentioned that, whilst fresh seed was only sown four times during the first 17 of the 35 years, it has been fully or partially sown 16 times during the last 18 years. It is obvious, therefore, that the plant was able to stand very much longer in the earlier than in the later condition of the soil. Indeed, both the reduced persistence of the plant, and the reduced produce, have been coincident with a considerable reduction in the stock of nitrogen in the soil.

The question arises—what relation does the amount of nitrogen lost by the soil, bear to the amount taken off in the crops?

It is admittedly necessary to accept with some reservation results of calculations of produce per acre, from amounts obtained on a few square yards, but the general indications may doubtless be trusted. Such estimates show more than 160 lbs. of nitrogen to have been removed per acre per annum in the crops, over the 21 years; whilst the estimated loss of the surface-soil corresponds to about 130 lbs. per acre per annum. That is to say, the loss by the surface-soil is sufficient to account for rather more than three-fourths of the amount of nitrogen removed in the crops.

There is, however, evidence leading to the conclusion that, in the case of soils to which excessive amounts of farmyard manure are applied, as, for instance, to such a garden soil, there may be some loss by the evolution of free nitrogen; and obviously so far as this may have occurred in the garden soil, there will be the less of the ascertained loss to be credited to assimilation by the growing Clover.

On the other hand, it is known that when growing on ordinary arable soil, the Clover plant throws out a large amount of feeding root in the lower layers; and although in the case of so rich a surface soil the plant may derive a larger proportion of its nutriment from that source, we must at the same time suppose that it has also availed itself of the resources of the subsoil. Unfortunately, in 1857 samples were only taken to the depth of nine inches, so that no comparison can be made of the condition of the subsoil at the two periods. It may be observed; however, that in 1879 the second nine inches showed about three times as high a percentage of nitrogen as the subsoils of the arable field at the same depth; indeed nearly twice as high a percentage as some of the exhausted arable surface-soils. It cannot be doubted, therefore; that the subsoil of the garden plot has contributed nitrogen to the Clover crops.

Here then, notwithstanding the very little effect of direct nitrogenous manures, on either the Beans or the Clover, on the ordinary arable land, there would seem to be very clear evidence of a soil-source of, at any rate much, if not indeed of the whole, of the enormous amounts of nitrogen assimilated over a given area by the Clover growing on the rich garden soil.

PRODUCE OF NITROGEN IN THE MIXED HERBAGE OF GRASS LAND.

The results in Table XI. afford evidence in the same direction.

TABLE XI.
EXPERIMENTS ON THE MIXED HERBAGE OF PERMANENT GRASS LAND.

The Park, Rothamsted.
Results showing the effects of Potash, on the development of Leguminosæ, and on the yield of Nitrogen in the crops.

Plots.	Conditions of Manuring.	Mean per cent. according to botanical separations at 6 periods, 1862, '67, '71, '72, '74, '75.			Average produce per acre per annum, 20 years, 1856-'75, according to mean per cent. of the 6 separations.			Average Nitrogen per acre per annum.		
		Gram-ineæ.	Legum-inosæ.	Other Orders.	Gram-ineæ.	Legum-inosæ.	Other Orders.	10 years 1856-1865.	10 years 1866-1875.	20 years 1856-1875.
3	Unmanured	p. c. 70·94	p. c. 8·17	p. c. 20·89	lbs. 1690	lbs. 195	lbs. 498	lbs. 35·1	lbs. 30·9	lbs. 33·0
4-1	Superphosphate*	68·17	5·68	26·15	1699	142	652	35·7	31·6	33·6
8	Complex Min. Man.†	73·71	8·43	17·86	2489	285	603	54·4	38·5	46·5
7	Complex Min. Man.‡	66·92	19·13	13·95	2649	757	552	55·2	58·0	56·6

* Plot 4-1, botanical separations at 4 periods only, namely 1862, 1867, 1872, and 1875.

† Including Potash, 6 years, 1856-61, excluding Potash, 14 years, 1862-1875.

‡ Including Potash every year.

As stated in the title of the Table, the results show, in the case of experiments on the mixed herbage of grass-land, the effects of potash on the development of the Leguminosæ, and on the yield of nitrogen in the crop. Results are given for four plots—one without any manure; one with superphosphate of lime alone; one with a complex mineral manure, including potash for six years, but excluding potash for the succeeding 14 years; and lastly, one with the complex mineral manure, including potash every year of the twenty.

The first set of three columns shows the average percentage of gramineous, leguminous, and miscellaneous herbage, in the produce, according to botanical separations made in six, or in four seasons, as stated; the second set the average produce per acre over 20 years, of each of these descriptions of herbage; and the last three columns show the amounts of nitrogen, per acre per annum, in the mixed produce, over the first 10, the second 10, and the total period of 20 years.

It is seen that on plot 8, with only a temporary supply of potash, the percentage of leguminous herbage in the produce is higher than on plot 4-1 with superphosphate of lime alone; but that, on plot 7, with the continuous supply of potash, it is more than twice as high. Thus, the percentage of leguminous herbage is—on plot 4-1, 5·68; on plot 8, 8·43; but on plot 7, 19·13.

The middle column of the second division shows that the estimated amounts of leguminous herbage per acre per annum were—on plot 4-1 without any potash 142 lbs., on plot 8 with partial supply of potash 285 lbs., and on plot 7 with the continuous supply 757 lbs.

Turning to the yield of nitrogen on the different plots, it is seen that the amounts are almost identical without manure, and with superphosphate of lime alone, namely, about 33 lbs. per acre per annum. On plot 8, where a complex mineral manure, including potash six years, but excluding it fourteen years, was employed, the yield of nitrogen is raised to 46·5 lbs. ; and on plot 7, which received the mixed mineral manure, including potash every year of the twenty, the yield is 56·6 lbs. per acre per annum. Further, without manure, and with superphosphate of lime alone, there was a decline in the yield of nitrogen in the later, compared with the earlier years. With the mineral manure, including potash in the first six years only, there was a much more marked decline. With the mineral manure, including potash every year, there was, on the other hand, even a slight tendency to an increased yield of nitrogen, in the later years.

Thus, then, it is estimated that the plot receiving potash every year, yielded over a period of twenty years, an average of 23·6 lbs. more nitrogen per acre per annum than the unmanured plot, and this increased yield was associated with an increased growth of Leguminous herbage. Whence comes the 23·6 lbs. more nitrogen annually taken up per acre on the mineral manured than on the unmanured plot? The results in Table XII. will afford evidence on this point.

TABLE XII.
PERMANENT MEADOW LAND SOILS.

Nitrogen, per cent. and per acre, in fine soil, dried at 100° C.

						1870.	1876.	1878.
						Per cent.	Per cent.	Per cent.
Plot 3.	Unmanured	..	..	..	..	0·2517	0·2466	
Plot 7.	Mixed Mineral Manure, including Potash	..	..	..	..		0·2236	0·2246
Difference							0·0230	
							lbs.	
Difference per acre {						Total 20 years ..	506·0	
						Average per annum ..	25·3	

After 20 years of continuous experiment, samples of soil were taken at three places on each of the experimental plots, and the Table shows the means of determinations of nitrogen in the surface-soils of the unmanured plot, and of the plot receiving the complex mineral manure (including potash), every year. Some control results are also given. Thus, determinations made in samples of the unmanured soil collected in 1870, control those in the samples collected in 1876, after the crops of five more years had been removed ; and, again, the results obtained on samples collected from the mineral manured plot in 1878, control and confirm those obtained on the samples taken in 1876.

Referring to the main figures, those relating to the samples taken in 1876, it is seen, that whilst the percentage of nitrogen in the surface-soil of the unmanured plot was 0·2466, it was in that of the mineral

manured plot, which had yielded so much more nitrogen in the crops, only 0.2236 per cent., or nearly one-tenth less.

Calculated per acre, the surface-soil of the mineral manured plot, to the depth of nine inches, contained, at the end of the twenty years, 506 lbs. less nitrogen than that of the unmanured plot to the same depth ; corresponding to an annual reduction of 25.3 lbs. per acre per annum.

Without pretending to claim absolute accuracy for such results, and such calculations, it is, to say the least, a very remarkable coincidence, that whilst the estimated increased yield of nitrogen per acre per annum, in the mineral manured crop was 23.6 lbs., the estimated increased loss of nitrogen by the surface soil should be 25.3 lbs. per acre per annum.

In reference to the fact that, according to the results, the resources of the surface soil would seem to have been mainly, if not wholly, drawn upon, it should be observed, that the potash of artificial manures is almost exclusively retained in the superficial layers of the soil, and that the leguminous plant that was the most prominently developed was the *Lathyrus pratensis*, which, although it has also deep roots, throws out an enormous quantity of feeding root near the surface ; whilst the prominent plants of other families were also those characterised by superficial rooting.

Here, again, then, in these results with the mixed herbage of grass land, as in those with the Clover on the rich garden-soil, there seems to be clear indication that the soil is an important source of nitrogen to Leguminosæ.

The next illustrations will bring to view the curious result that, on soil where one leguminous plant has practically failed, another plant of the same family may grow luxuriantly, and in some way obtain very large amounts of nitrogen.

RED CLOVER GROWN AFTER BEANS.

The experiments to which I have now to direct attention, were made in the field which had been devoted to experiments on the growth of beans for a period of 32 years ; but which, as has been seen, so far failed that an average crop was seldom obtained ; whilst the amount of nitrogen taken up over a given area, though still much more than in *non*-Leguminous crops grown under similar conditions, was, after the first few years, much below the amount in a fairly average Bean-crop. After the cessation of the experiment with Beans in 1878, the land was left fallow for between four and five years, to 1882 inclusive, when Grass-seeds were sown, but failed. On this land, on which the attempt to grow the Leguminous-crop—*Beans*—had been abandoned, Barley and Clover were sown in the spring of 1883.

Before considering the results of this new experiment, it will be well briefly to call attention to the direct experimental evidence as to the condition of the soils. Thus, in April, 1883, before the Barley and Clover were sown, the surface-soil (free of stones, and reckoned

dry) of the plot which had been entirely unmanured during the 32 years of the experiments with the Beans, contained 0·0993 per cent. of nitrogen, that of the mineral manured plot 0·1087 per cent., and that of the plot which had received both the mineral and nitrogenous manure 0·1163 per cent., amounts which show considerable nitrogen exhaustion of the surface-soil.

Also in 1883, the nitrogen as nitric acid was determined in samples, each of 9 inches of depth, down to a total depth of 72 inches. In the case of several plots, the results show, calculated per acre, that the total amount of nitrogen as nitric acid to the depth of 8 times 9 inches, or 72 inches in all, was 27·95 lbs. in the unmanured plot, 20·72 in that with purely mineral manure, and 25·38 lbs. in that of the plot which had received both mineral and nitrogenous manure. In the soil of the farm-yard manure plot, on the other hand, the amount was about twice as much—namely 50·46 lbs. Excluding this last result, it may be said that the amounts of nitrogen already existing as nitric acid, to the depth determined, were very small.

These, then, were the conditions of the soil when the Barley and Clover were sown in the spring of 1883. The Clover grew very luxuriantly from the first, so much so as considerably to interfere with the growth of the Barley.

Table XIII. (below), shows the amounts of nitrogen per acre in the Barley and Clover in 1883, and in the Clover in 1884 and 1885.

TABLE XIII.
BARLEY AND CLOVER, GROWN AFTER BEANS.
Geescroft Field.

Nitrogen removed per acre in the Crops.

Previous Condition of Manuring.	1883. Barley and Clover.	1884. Clover.	1885. Clover.	Total.
	lbs.	lbs.	lbs.	lbs.
Without Manure	45·0	183·2	52·7	280·9
Mineral Manure and some Nitrogen	57·2	193·1	79·9	330·2
Mineral Manure only	59·3	206·4	81·6	347·3

It should be stated that the plots, the yield of nitrogen of which is here given, do not exactly correspond with those for which the yield of nitrogen in the Beans was given; some of the Barley and Clover crops having been taken together where no difference in the produce was observable. Thus, half the plot represented as without manure, had been unmanured from the commencement, that is for nearly 40 years, but the other half received some nitrogen to 1878 inclusive, but had since been entirely unmanured. Again, the results given in the second line relate to the produce of a plot part of which received purely mineral manure, but the other part ammonium-salts or nitrate up to 1878, but none since. The results given in the third line relate, however, to a plot which has not received any nitrogenous manure from the commencement of the experiments with the Beans, but which

was not brought under experiment until 5 years later than the other plots.

Thus, on a plot where a purely mineral manure containing potash, but no nitrogen, had been applied for 27 years, to 1878 inclusive, and no manure since, 347·3 lbs. of nitrogen were gathered per acre, almost wholly by the Leguminous crop—Clover. On a plot on part of which the mineral only, and on part the same mineral manure and ammonium-salts or nitrate had been applied up to 1878, but nothing since, 330·2 lbs. of nitrogen were removed in the crops. Lastly, where, to half of the plot no manure whatever had been applied for nearly 40 years, but to the other half ammonium-salts or nitrate had been applied up to 1878, the yield of nitrogen in the Barley and Clover was 280·9 lbs.

Here, then, in a field where Beans had been grown for many years in succession, and had yielded much less than average crops, and the land had then been left fallow for several years; where the surface-soil had become very poor in total nitrogen; where both surface and sub-soil were very poor in ready-formed nitric acid; and where there was a minimum amount of crop residue near the surface for decomposition and nitrification, there were grown very large crops of clover, containing very large amounts of nitrogen.

Not only was so much nitrogen removed in the crops, but the surface-soils became determinably richer in nitrogen, as the results in Table XIV. (below) show. There are there given, the percentages of nitrogen in the sifted dry surface-soil of the three plots for which the produce and the nitrogen in the Beans have been given. The results relate to samples taken in April 1883, before the sowing of the Barley and Clover, and in November 1885, after the removal of the crops. The first two columns show the percentages of nitrogen, and the other columns the calculated amounts of nitrogen per acre, in the surface-soils, 9 inches deep, at the different dates, and the estimated gain of nitrogen under the influence of the growth of the clover.

TABLE XIV.

Nitrogen, per cent. and per acre, in the surface-soils, before and after the growth of the Barley and Clover.

	Nitrogen in sifted dry soil.				
	Per cent.		Per acre.		
	1883.	1885.	1883.	1885.	1885 + or - 1883.
	Per cent.	Per cent.	lbs.	lbs.	lbs.
1. Without Manure	0·0993	0·1083	2441	2662	+ 221
2. { With Mineral Manure containing Potash }	0·1087	0·1149	2672	2824	+ 152
3. { With Mineral Manure and Nitrogen }	0·1163	0·1225	2859	3011	+ 152

Without assuming that the figures represent accurately the amounts of nitrogen accumulated per acre, it cannot be doubted that the

surface-soils had become considerably richer. If, for the sake of illustration, we assume that 300 lbs. of nitrogen were removed per acre in the crops, and that 150 lbs. were accumulated in the surface-soil, we have 450 lbs. of nitrogen to account for, as gathered by the crops within a period of little more than two years.

It is clear that we have in the experimental results themselves no conclusive evidence as to the source of so large an amount of nitrogen. As the surface-soil became determinably richer, it is obvious that it must have been derived either from above or below it—from the atmosphere, or from the sub-soil; and, if from the sub-soil, the question arises—whether it was taken up as nitric acid, as ammonia, or as organic nitrogen? I shall have to adduce evidence bearing on these points further on; but it must be admitted that there is nothing in the experimental results themselves, to show that so large an amount of nitrogen could have been available as nitric acid.

VARIOUS LEGUMINOUS PLANTS GROWN AFTER RED CLOVER.

I have now to adduce another, and even much more striking instance, of successful growth, and of great accumulation of nitrogen, by plants of the Leguminous family, on soil where another plant of the same family had failed, and where the surface-soil had become very poor in nitrogen.

The experiments were made on the plots where it had been attempted to grow Red Clover year after year on the same land; where, in fact, Clover had been sown 12 times in 30 years, and where, in 8 out of the last 10 trials, the plant had died off in the winter and spring succeeding the sowing of the seed; in 4 cases without any crop at all, and in the other 4 yielding very small cuttings.

In 1878, the land was devoted to experiments with various Leguminous plants, differently manured, having regard, however, to the previous manorial history of the plots.

The object was to ascertain whether, among a selection of plants all belonging to the Leguminous family, but of different habits of growth, and especially of different character and range of roots, some could be grown successfully for a longer time, and would yield more produce, containing more nitrogen, as well as other constituents, than others; all being supplied with the same descriptions and quantities of manuring substances, applied to the surface-soil. Further, whether the success in some cases, and the failure in others, would afford additional evidence as to the source of the nitrogen of the Leguminosæ generally, and as to the causes of the failure of Red Clover when grown too frequently on the same land.

Accordingly, 14 different *Leguminosæ* were selected, and sown in 1878. These included 8 species or varieties of *Trifolium*, 2 species of *Medicago*, *Melilotus leucantha*, *Lotus corniculatus*, *Vicia sativa*, and *Lathyrus pratensis*. Of these, 6 of the 8 *Trifoliums* have already failed, and been replaced by other plants; as also have the *Medicago*

lupulina, the *Lotus corniculatus*, and the *Lathyrus pratensis*; the last being replaced in the second year by *Onobrychus sativa*. The plants which have maintained fair, but very varying character of growth, are the *Trifolium repens*, *Vicia sativa*, *Melilotus leucantha*, and *Medicago sativa*; and I propose to give some account of the growth of these plants on this Clover-exhausted soil.

That the surface-soil had become very poor in nitrogen is evident from the fact, that the mean percentage of it in the sifted dry surface-soil of 5 of the Clover plots was, in March 1881, only 0.1058, which is considerably lower than was found in the same field many years before, and lower than has been found in any of the fields at Rothamsted excepting those where crops have been grown for many years on the same land without nitrogenous manure. It is a point of interest, however, that the percentage in the surface-soil is not so low as in immediately adjoining land, which has been under alternate Wheat and Fallow for nearly 30 years without manure.

The real interest of the results depends on the amounts, and on the difference in the amounts, of nitrogen, which the various plants have assimilated over a given area, all growing side by side on the same Red-clover-exhausted land, and with the same mineral manures, without any nitrogen supply.

Accordingly, the upper part of Table XV. (p. 32) shows the estimated average amounts of nitrogen in the Gramineous crop, Wheat, grown in alternation with Fallow, over 27 years to 1877 inclusive, and in the Red-clover, (together with other crops when it failed) over 29 years, also to 1877 inclusive. Then, in the body of the Table are given, the amounts of nitrogen in the Wheat alternated with Fallow, and in the produce of five different Leguminous plants, during the subsequent years, commencing with 1878, and ending with 1888.

Thus, over the preliminary period, the Wheat gave an average annual yield of nitrogen per acre of 17 lbs., and the Clover gave, over much the same period, an average of 32 lbs. of nitrogen.

Against these amounts, the various crops yielded, over the subsequent years, averages as follows:—The Fallow Wheat, over 11 years, 12 lbs.; the Red Clover (*Trifolium pratense*), over 8 years, 14 lbs.; the White Clover (*Trifolium repens*), over 11 years, 26 lbs.; the Vetch (*Vicia sativa*), over 11 years, 77 lbs.; the Bokhara Clover (*Melilotus leucantha*), 62 lbs.; and the Lucerne (*Medicago sativa*), over 11 years, 136 lbs.

Or, if we take the average amounts over the years of actual crop only, the amounts were—in the Wheat 22 lbs., in the Red Clover 22 lbs., in the White Clover 47 lbs., in the Vetch 77 lbs., in the Bokhara Clover 68 lbs., and in the Lucerne the enormous amount of 166 lbs., of nitrogen per acre per annum.

Again, if we take the total yields of nitrogen over the experimental periods, we have, in the Wheat 133 lbs., in the Red Clover 112 lbs., in the White Clover 283 lbs., in the Vetch 846 lbs., in the Bokhara Clover 679 lbs., and in the Lucerne 1,492 lbs.; that is, in the Lucerne

about eleven times as much as in the Wheat, and more than thirteen times as much as in the Red Clover. Indeed, this very deeply, and very powerfully rooting plant, yielded, in its above-ground produce alone, 337 lbs. of nitrogen in 1884, 270 lbs. in 1885, 167 lbs. in 1886, 247 lbs. in 1887, and 161 lbs. in 1888.

TABLE XV.

Estimated yield of Nitrogen per acre, in lbs., in Wheat alternated with Fallow, and in various Leguminous Crops, without Nitrogenous Manure.

		Un-manured Fallow Wheat.	Mineral Manures only.				
			Trifolium pratense.	Trifolium repens.	Vicia sativa.	Melilotus leucantha	Medicago sativa.
PRELIMINARY PERIOD. WHEAT AND FALLOW, 27 yrs., 1851-'77. RED CLOVER, &c., 29 yrs., 1849-'77.							
Average per acre per annum ..		lbs. 17	lbs. 32				
EXPERIMENTAL PERIOD.							
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1878		29	0	0	51	53	0
1879	Fallow	50	82	46	130	0	
1880	24	8	0	58	36	28	
1881	Fallow	21	8	65	60	28	
1882	18	18	74	146	145	111	
1883	Fallow	0	0	101	27	143	
1884	29	0	0	113	56	337	
1885	Fallow	15	97	90	58	270	
1886	14	Lupins	16	52	0	167	
1887	Fallow	0	6	64	82	247	
1888	19 {	Medicago sativa }	0	60	32	161	
Total, 11 years, 1878-'88..		133	112*	283	846	679	1492
Average, 11 years, 1878-'88		12	14*	26	77	62	136
Average for years of crop		22	22	47	77	68	166

* Eight years only, 1878-'85.

Not only have these large amounts of nitrogen been removed in the above-ground produce, but determinations of nitrogen in the surface-soils of the Vetch plot in 1883, and of the White Clover, the Bokhara Clover, and the Lucerne plots, in 1885, have shown, as in the case of the Clover after the Beans, that the surface-soil has gained rather than lost nitrogen, due to the accumulation of nitrogenous crop-residue. Here again, then, it is obvious, that the original source of the nitrogen of the crops has not been the surface-soil. It must have been derived either from the atmosphere or from the sub-soil.

The next results will throw some light on this point. Thus, having made initiative experiments of the same kind some years previously, in July, 1883, samples of soil were taken to the depth of 12 times 9 inches, or 108 inches in all, on the Wheat fallow plot, on the White Clover plot, and on two of the Vetch plots, for the determination of the

amount of nitrogen existing as nitric acid, at each depth. Table XVI. summarises the results.

TABLE XVI.

Nitrogen as Nitric Acid, per acre, lbs., in soils of some experimental plots, without Nitrogenous Manure for more than 30 years.

Hoosfield, Rothamsted.

Samples collected July 17-26, 1883.

Depths.	Wheat-Fallow Land. Unmanured.	Trifolium repens. Series 1. Plot 4.	Vicia sativa. Series 1. Plot 4.	Vicia sativa. Series 1. Plot 6.	Trifolium repens + or - Wheat Land.	+ or - Trifolium repens.	
						Vicia sativa. Plot 4.	Vicia sativa. Plot 6.
Inches.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1-9	19·85	30·90	12·16	10·22	+ 11·05	— 18·74	— 20·68
10-18	8·05	27·73	4·11	2·72	+ 19·68	— 23·62	— 25·01
19-27	2·47	8·44	1·37	1·08	+ 5·97	— 7·07	— 7·36
28-36	2·70	7·64	1·67	1·52	+ 4·94	— 5·97	— 6·12
37-45	1·62	9·07	4·58	2·51	+ 7·45	— 4·49	— 6·56
46-54	3·57	8·77	6·37	4·42	+ 5·20	— 2·40	— 4·35
55-63	3·84	7·92	7·16	4·52	+ 4·08	— 0·76	— 3·40
64-72	2·28	8·34	5·95	4·92	+ 6·06	— 2·39	— 3·42
73-81	1·48	8·27	4·54	4·81	+ 6·79	— 3·73	— 3·46
82-90	1·76	9·95	5·32	5·14	+ 8·19	— 4·63	— 4·81
91-99	2·94	9·16	5·66	6·40	+ 6·22	— 3·50	— 2·76
100-108	1·84	9·51	5·32	6·46	+ 7·67	— 4·19	— 3·05

SUMMARY.

1-27	30·37	67·07	17·64	14·02	+ 36·70	— 49·43	— 53·05
28-54	7·89	25·48	12·62	8·45	+ 17·59	— 12·86	— 17·03
55-81	7·60	24·53	17·65	14·25	+ 16·93	— 6·88	— 10·28
82-108	6·54	28·62	16·30	18·00	+ 22·08	— 12·32	— 10·62
1-54	38·26	92·55	30·26	22·47	+ 54·29	— 62·29	— 70·08
55-108	14·14	53·15	33·95	32·25	+ 39·01	— 19·20	— 20·90
1-108	52·40	145·70	64·21	54·72	+ 93·30	— 81·49	— 90·98

The first point to notice is that, at each depth, from the first to the twelfth, the *Trifolium repens* soil contains much more nitrogen as nitric acid than the Wheat fallow soil; and, as the figures at the bottom of the Table show, whilst to the total depth of 108 inches, or 9 feet, the Wheat fallow soil is estimated to contain per acre only 52·4 lbs. of nitrogen as nitric acid, the *Trifolium repens* soil, that is the Leguminous plant soil, contained to the same depth 145·7 lbs.

Now, independently of the fact that the Leguminous plant plots had received mineral manures, and the Wheat land had not, the characteristic difference in the history of the two plots was, that the one had, from time to time grown a Leguminous crop, and the other had not, and the one which had grown Leguminous crops contained, to the depth of 9 feet, nearly 3 times as much nitrogen as nitric acid as the Gramineous crop soil.

The difference is the greatest near the surface, but it is very considerable down to the lowest depths. In the first three depths,

there is more than twice as much nitrogen as nitric acid in the *Trifolium repens*, as in the Wheat fallow soil; in the second and third 3 depths, there is more than 3 times; and in the fourth 3, more than 4 times as much. Hence it is obvious, that any loss by drainage would be much the greater from the *Trifolium* plot, so that the difference between the two plots was probably greater than the figures show.

In the case of both plots the actual amount of nitrogen as nitric acid is the greatest near the surface, indicating more active nitrification; and the greater amount in the *Trifolium* soil is doubtless due to more nitrogenous crop-residue from the Leguminous than from the Gramineous crop. Indeed, as Table XV. (p. 32) shows, about 74 lbs. of nitrogen had been removed in the *Trifolium repens* crops, and only 18 lbs. in the Wheat, in 1882, and none from either in 1883, the year of soil sampling; and the crop-residue of the *Trifolium repens* would contain much more nitrogen than that of the Wheat. But it is not probable that the excess of nitric acid in the *Trifolium* soil, together with the larger amount lost by drainage, could be entirely due to the nitrification of recent crop-residue. Some found in the lower layers is, however, doubtless due to washing down from the surface. But as, notwithstanding much more nitrogen had been removed in the crops from the Leguminous than from the Gramineous crop land during the preceding 30 years, the surface-soil of the Leguminous plot remained slightly richer in nitrogen, it is obvious that the whole of the nitrogen of the nitric acid could not have had its origin in the surface-soil. If, therefore, it did not come from the atmosphere, it has been derived from the sub-soil.

The indication is, that nitrification is more active under the influence of Leguminous than of Gramineous growth and crop-residue. There would not only be more nitrogenous matter for nitrification, but it would seem that the development of the nitrifying organisms is the more favoured. Part of the result may, therefore, be due to the passage downwards of the organisms, and the nitrification of the organic nitrogen of the sub-soil.

An alternative is, that the soil and the sub-soil may still be the source of the nitrogen, but that the plants may take up, at any rate part, as ammonia, or as organic nitrogen. To this point I shall recur presently.

Comparing the amounts of nitrogen as nitric acid in the *Vicia sativa* soils, with those in the *Trifolium repens* soil, it is to be observed, that whilst from the *Trifolium repens* soil only 164 lbs. of nitrogen had been removed per acre in the crops of the five years to 1882 inclusive, 366 lbs. had been removed in the *Vicia* crops to the same date. Then, whilst none was removed in crops from the *Trifolium* plot in 1883, 101 lbs. were removed in the *Vicia* crops just before soil-sampling. Under these circumstances, one of the *Vicia* soils contains 81.5 lbs., and the other 91 lbs., less nitrogen as nitric acid per acre, than the *Trifolium repens* soil.

Of course we cannot know exactly how much was at the disposal of

the plants at the commencement of growth ; but if there had only been as much as in the case of the *Trifolium* plot, it is seen that the deficiency in the *Vicia* soils nearly corresponds with the amount removed in the crop, which was 101 lbs. It may at any rate safely be concluded, that most, if not the whole, of the nitrogen of the *Vicia* crops, had been taken up as nitric acid.

But as the *Vicia* crops had removed much more in the preceding years than the *Trifolium* crops, so also would their crop-residue be greater ; and, in fact, much more nitrogen must have been taken up by the plants each year than the figures show ; and the larger the crop-residue, the larger would be the amount of nitric acid for each succeeding crop. But the crop of 1883 was also large, and it would leave a correspondingly large nitrogenous crop-residue ; leaving, therefore, a large amount of the nitrogen assimilated to be otherwise accounted for than by previous crop-residue.

Lastly in reference to these experiments, it is seen that, at each of the 12 depths, the *Vicia* soils with growth, contained much less nitric acid than the *Trifolium* soil without growth ; and the difference is much the greatest in the upper 4 or 5 depths, within which the *Vicia* throws out by far the larger proportion of its feeding roots ; but the deficiency is quite distinct below this depth ; the supposition being that, under the influence of the growth, water had been brought up from below, and with it nitric acid. In fact, the determinations showed that, down to the depth of 108 inches, the *Vicia* soils contained less water than the *Trifolium* soil, in amount corresponding to between 6 and 7 inches of rain, or to between 600 and 700 tons of water per acre.

Experiments of the same kind were again made in 1885. *Trifolium repens* was again selected as the weak and superficially rooting plant, *Melilotus leucantha* as a deeper and stronger rooting one, and the *Medicago sativa* as a still deeper, and still stronger rooting plant. Samples of soil were taken at the end of July and the beginning of August, from 2 places on each plot, and, in each case, as before, to 12 depths of 9 inches each, or to a total depth of 108 inches, or 9 feet. It will suffice to quote the results for the *Trifolium repens* and the *Medicago sativa* plots. They are given in Table XVII. (p. 36).

It is seen that there was much less nitrogen as nitric acid in the *Trifolium* soil in 1885, after the removal of 97 lbs. in the crops, than in 1883 (see Table XVI., p. 33), when there had been no crop. The deficiency is the greatest in the two upper layers, but it extends to the fifth depth, representing the range of the direct and indirect action of the superficial roots. Below this point there is, however, even more than in 1883 ; due, doubtless, in part to percolation from above during the two preceding seasons without growth, and possibly in part to percolation of the nitrifying organisms, and the nitrification of the nitrogen of the sub-soil.

Let us now compare the results relating to the *Medicago sativa* with those relating to the *Trifolium repens* soils.

TABLE XVII.

Nitrogen as Nitric Acid, per acre, lbs., in the soils and sub-soils of some experimental plots, without Nitrogenous Manure for more than 30 years.

Hoosfield, Rothamsted.

Samples collected July 29 to August 14, 1885.

Depths.	Series 1. Mineral Manures.		
	<i>Trifolium repens</i> . Plot 5.	<i>Medicago sativa</i> . Plot 5.	<i>Medicago sativa</i> + or — <i>Trifolium repens</i> .
Inches.	lbs.	lbs.	lbs.
1-9	11.50	8.88	— 2.62
10-18	1.38	1.11	— 0.27
19-27	0.90	0.78	— 0.12
28-36	1.86	0.81	— 1.05
37-45	7.08	0.99	— 6.09
46-54	11.31	0.93	— 10.38
55-63	13.14	0.57	— 12.57
64-72	12.63	0.81	— 11.82
73-81	11.19	0.70	— 10.49
82-90	10.70	0.61	— 10.09
91-99	11.08	0.44	— 10.64
100-108	9.96	0.41	— 9.55
Total ..	102.73	17.04	— 85.69
SUMMARY AND CONTROL.			
1-9	11.50	8.88	— 2.62
10-18	1.38	1.11	— 0.27
Mixture of 19-108 inches }	88.02	6.97	— 81.05
Total ..	100.90	16.96	— 83.94

The Table of the estimated nitrogen in the produce per acre (p. 32), shows that, whilst from the commencement to 1885 inclusive, the *Trifolium repens* yielded only 261 lbs. of nitrogen in crops, the *Medicago* gave 917 lbs.; and again, whilst in 1885, the year of soil-sampling, the *Trifolium* gave only 97 lbs., the *Medicago* gave 270 lbs. It is further to be observed that, quite accordantly with the usual character of growth of Lucerne in agriculture, with the increasing root-range, and consequently increased command of the stores of the soil and sub-soil, the yield of nitrogen increased from 28 lbs. in the first and second years, to 337 lbs. in the fifth year of growth, declining, however, somewhat afterwards.

Under these circumstances of very large yields of nitrogen in the crops, there is, at every one of the twelve depths, less, and at most very much less, nitrogen as nitric acid remaining in the soil than where so much less had been removed in the *Trifolium repens* crops. The difference is distinct even in the upper layers; but it is very striking in the lower depths. Thus, there is, on the average, not one-twelfth as much nitric-nitrogen in the lower 10 depths of the soil of the deep-rooting and high-nitrogen yielding *Medicago sativa*, as in those of

the shallow-rooting and comparatively low nitrogen yielding *Trifolium repens*. Indeed, the nitric acid is nearly exhausted in the deep-rooting *Medicago sativa* plot; there remaining, to the total depth of 9 feet, only about 17 lbs. of nitric-nitrogen, against more than 100 lbs. to the same depth in the *Trifolium repens* soil. The total deficiency of nitric-nitrogen in the *Medicago* as compared with the *Trifolium repens* soil, is seen to be 85.69 lbs. according to one set of determinations, and 83.94 lbs. according to the other.

As already said, we cannot know what was the stock of nitric-nitrogen in the soil at the commencement of the growth of the season, or the amount formed during the growing period. But, with so much more *Medicago* growth for several previous years, it seems reasonable to assume that there would be much more nitrogenous crop-residue for nitrification than in the case of the *Trifolium repens* plot.

But even supposing, for the sake of illustration, that each year's growth would leave crop-residue yielding an amount of nitrogen as nitric acid for the next crop, or succeeding crops, approximately equal to the amount which had been removed in the crop, the increasing amounts of nitrogen yielded in the crops from year to year could not be so accounted for; and there would remain the amount of nitrogen in the crop-residue itself, still to be provided in addition. In fact, assuming the proportion of nitrogen in the crop-residue to that in the removed crop to be as supposed in the above illustration, nearly 700 lbs. of nitrogen would have been required for the *Medicago* crop and crop-residue of 1884; or, if we assume the nitrogen in the residue to be only half that in the crop, about 500 lbs. would have been required. Doubtless, however, some of the nitrogenous crop-residue would accumulate from year to year.

The results can leave no doubt that the *Trifolium repens*, and the *Medicago sativa*, have each taken up much nitrogen from nitric acid within the soil, and that, in fact, nitric acid is an important source of the nitrogen of the Leguminosæ. Indeed, existing direct experimental evidence relating to nitric acid, carries us quantitatively further than any other line of explanation. But, it is obviously quite inadequate to account for the facts of growth, either in the case of the *Medicago sativa* after the Clover, or in that of the Clover after the Beans.

It is obvious that, if nitric acid were the source of the whole, there must have been a great deal formed by the nitrification of the nitrogen of the sub-soil. A difficulty in the way of the assumption that nitric acid is the exclusive, or even the main source of the nitrogen of the Leguminosæ is, that the direct application of nitrates as manure, has comparatively little effect on the growth of such plants. In the case of the direct application of nitrates, however, the nitric acid will percolate chiefly as sodium or calcium nitrate, unaccompanied by the other necessary mineral constituents in an available form; whereas, in the case of nitric acid being formed by direct action on the sub-soil, it is probable that it will be associated with other constituents, liberated, and so rendered available, at the same time.

EXPERIMENTS ON THE NITRIFICATION OF SOILS AND SUB-SOILS.

It was obviously important to determine by direct experiment, whether the nitrogen existing in a comparatively insoluble condition in raw clay sub-soil, was susceptible of nitrification.

It had already been found at Rothamsted, that the sub-soils of rich Prairie-land were subject to nitrification; but considering the conditions of the collection and transmission of the samples in question, it was considered possible that comparatively recent organic matter from the surface-soil might not have been entirely excluded. Accordingly, experiments were made with some of the Rothamsted raw clay sub-soils.

The percentages of total nitrogen in the samples was determined. The nitrogen as nitric acid was determined in the dry sifted soil, both before and after exposure for some months under suitable conditions as to temperature and moisture. After the first extraction, the soils were seeded with from 0.1 to 0.2 gram of rich garden-soil, assumed to contain nitrifying organisms, and by 0.2 gram more after some subsequent extractions. Further, after 3 or 4 extractions, which had of course removed the soluble mineral matters, a mineral mixture was added.

The results have been given and discussed in detail elsewhere, and their general indication may be stated as follows:—Results obtained with raw, and mostly clay, sub-soils, which contain not more than 6 or 8 parts of carbon to 1 of nitrogen, confirm those previously obtained with Prairie sub-soils containing a much higher proportion of carbon, in showing that their nitrogen is susceptible of nitrification, provided the organisms, and other essential conditions, are not wanting. The results also consistently showed, that there is more active nitrification in Leguminous than in Gramineous crop sub-soils. This, it must be supposed, is partly due to more active development, and greater distribution, of the organisms themselves, under the influence of the Leguminous growth, with its excretions and residue, and partly to the greater actual amount of such easily changeable matters, with the greater amount of nitrogenous crop-residue.

The results are also confirmed by those of experiments made in the Rothamsted Laboratory by Mr. Warington, on quite distinct lines. His plan was to introduce a portion of the sub-soil into a sterilized nitrogenous liquid, and to determine whether nitrification took place; the result being taken to show whether or not the organisms were present in the sub-soil. From his first results he concluded that in our clay soils the nitrifying organism is not uniformly distributed much below 9 inches from the surface; that it is sparsely distributed down to 18 inches, or possibly somewhat further; but that at depths from 2 feet to 8 feet, there was no trustworthy evidence to show that the clay contained the nitrifying organism.

Subsequently, he experimented with a greater variety of sub-soils, and with some taken in the immediate neighbourhood of lucerne roots, and gypsum was added to the sterilized liquids.

Among the 69 experiments made in this new series, there was no failure to produce nitrification by samples down to 2 feet ; there was only one failure out of 11 trials down to 3 feet ; but below 3 feet, the failures were more numerous. Taken at 6 feet, about half the samples induced nitrification. The order of priority of nitrification diminished from the upper to the lower depths ; indicating more sparse occurrence, or more feeble power of development and action. There was, moreover, notably more active nitrification with the Leguminous than with the Gramineous crop sub-soils.

It is, then, established, that the nitrogenous matters of raw clay sub-soils are susceptible of nitrification, if the organisms, with the other necessary conditions, are present. It is further indicated, not only that the action is more marked under the influence of Leguminous than of Gramineous growth and crop-residue, but that the organisms become distributed to a considerable depth, even in raw clay sub-soils, especially where deep rooted and free growing Leguminosæ have developed.

The next question is, how far, in a quantitative sense, do the results aid us in explaining the source of the large amounts of nitrogen taken up by some Leguminous crops ?

In the case of three Leguminous crop sub-soils there was, over the total period, only about 1 part of nitrogen nitrified per million of soil ; and as the sub-soil, to the depth experimented on, would weigh about 30 million lbs. per acre, the amount of nitrification supposed would represent only about 30 lbs. of nitric-nitrogen per acre. Obviously the conditions of nitrification in which the samples are exposed in the Laboratory are very different from those of the sub-soil *in situ*. Thus, whilst in the case of the samples in the Laboratory, the conditions as to temperature, and, perhaps of aëration, would be the more favourable, the successive extractions by water under pressure, would be liable to remove, not only the mineral matters essential for the development of the organisms, and for the production of nitric acid, but the organisms themselves ; whereas, in the case of the natural sub-soil, the tendency would be to multiplication.

Compared with the small amount of nitrification of the nitrogen of the raw clay sub-soils shown in the foregoing experiments, some results obtained by Mr. Warington, in experiments in which he mixed raw clay sub-soil with an equal weight of coarsely powdered flint, seeded the mixture with rich garden-soil, moistened it, and placed it in a vessel allowing of free access of washed air, show, in one case 12·9 and in the other 11·8 parts of nitrogen nitrified per million of sub-soil ; and, when mineral plant food was added to the subsoils, the amounts of nitrogen nitrified were raised to 21·4, and 14·2, parts, per million. It is obvious, therefore, that there would be little difficulty in accounting even for the large amounts of nitrogen taken up by the *Medicago sativa* were it established, which it certainly is not, that coincidently with the deep-rooted growth, both the nitrifying organisms, and air, were abundantly present in the sub-soil.

Indeed, the greatest difficulty in the way of the supposition that much nitrogen is available to plants by the nitrification of the nitrogen of the sub-soil, is the want of sufficient aëration. Independently of the greater or less porosity of the sub-soil itself, and of the channels formed by worms, it is obvious that, wherever the roots go, water and its contents can follow; and that, with deep-rooted plants, and free growth, there will be active movement of water, and there must be of air also, in the lower layers of the soil. In experiments made in 1882, there remained in the *Melilotus* soil, less water than in the *Trifolium repens* soil where there had been less growth, in amount corresponding, down to a depth of 54 inches, to a loss of 540 tons per acre, or nearly $5\frac{1}{2}$ inches of rain; and, as already stated, in 1883, the *Vicia sativa* soils showed, down to 108 inches, less water than the *Trifolium repens* soil, in amount corresponding to between 600 and 700 tons per acre, or to between 6 and 7 inches of rain. Obviously too, the still deeper rooting, and still freer growing, *Medicago sativa*, would remove still more water.

Although much experiment, and much calculation, have been devoted by several investigators to the estimation of the degree of aëration of soils and sub-soils of different character, the data at command do not justify any very definite conclusions on the subject. The results seem to indicate a probable range of aëration from about 30 to over 50 per cent. of the volume of the soil. But these estimates do not take into account the varying amounts of water in the soil or sub-soil. In the case of the sub-soils above referred to, each layer of 9 inches in depth retained from about 2 to nearly 4 inches of water, the amount varying very much, according to the nature of the sub-soil, and especially according to the amount of growth, and the consequent withdrawal of water from below, and its evaporation, chiefly through the plant, but partly also from the surface soil. The amount must, obviously, also vary very much according to the character of the season.

It may be stated that, supposing the sub-soil contained at one time, air equal to one third of its volume, this would not suffice for the nitrification of as much nitrogen as was taken up each year, for several years in succession, by the *Medicago sativa*; or during the two years in the case of the Red-clover on the Bean-exhausted land. But the nitrogen is not taken up all at once, though much of it will be within a few months of the year, during which period there would be the most active withdrawal of water from below, and evolution by the plant, and evaporation by the surface-soil. The replacement of this sub-soil water by an equal volume of air would, however, still not suffice. The question obviously arises—how far, or how rapidly, the used up oxygen will be replaced, and on this point there is very little experimental evidence to aid us.

Thus, then, the evidence is clear, that the nitrogen of raw clay sub-soils, which constitutes an enormous store of already combined nitrogen, is susceptible of nitrification, provided the organisms are

present, and the supply of oxygen is sufficient; but the data at command do not justify the conclusion that these conditions would be adequately available in such cases as those of the very large accumulations of nitrogen by the Red-clover grown after the Beans, and of the increasing, and very large accumulations, by the *Medicago sativa*, for a number of years in succession.

The alternatives are—either that the plant may take up nitrogen from the sub-soil in some other way, as ammonia, or as organic nitrogen; or that the free nitrogen of the atmosphere is in some way brought under contribution.

CAN ROOTS, BY VIRTUE OF THEIR ACID SAP, ATTACK, AND RENDER AVAILABLE, THE OTHERWISE INSOLUBLE NITROGEN OF THE SUB-SOIL?

In reference to the first of the above alternatives, the question suggested itself whether roots, by virtue of their acid sap, may not, either directly take up, or at any rate attack and liberate for further change, the otherwise insoluble organic nitrogen of the sub-soil?

Accordingly, in the autumn of 1885, specimens of the deep, strong, fleshy root of the *Medicago sativa* were collected and examined; when it was found that the sap was very strongly acid. The degree of acidity of the juice was determined; and attempts were made so to free the extract from nitrogenous bodies as to render it available for determining whether or not it would attack and take up the nitrogen of the raw clay sub-soil. Hitherto, however, these attempts have been unsuccessful. But it may be of interest to state, as indicating the extent of the command of the sub-soil which such plants acquire, that, of the 3 plants collected, the roots of one had four branches, respectively, 6 feet 4½ inches, 5 feet 10½ inches, 3 feet 6½ inches, and 2 feet 9½ inches, in length; the second had two branches—4 feet 10, and 2 feet 2 inches, long; and the third two branches—3 feet 9, and 1 foot 9 inches, in length.

ACTION OF DILUTE ORGANIC ACID SOLUTIONS ON THE NITROGEN OF SOILS AND SUB-SOILS.

Experiments were next made to determine the action on soils and sub-soils, of various organic acids, in solutions of a degree of acidity either approximately the same as that of the *Medicago sativa* root-juice, or having a known relation to it. These experiments and their results have been fully detailed elsewhere, and only their general indications can be referred to here.

Obviously, however, the conditions of experiments in which an acid solution is agitated with a quantity of soil in a bottle, are not comparable with those of the action of living roots on the soil. The root action would necessarily affect only a very small proportion of the total soil. But the results showed, that the more nitrogen was taken up the greater the acidity of the solution, and the question arises,

whether the root action would not effect more resolution on the surfaces actually attacked. Indeed, this must necessarily be the case, if such an action is really quantitatively an important source of the nitrogen taken up by deep and strong rooting plants, with strongly acid-sap. In illustration of this necessity it may be stated that, even if as much as 20 parts of nitrogen were taken up per million of soil, as was the case in some of the experiments, this would only represent 600 lbs. of nitrogen per acre to the depth examined, namely, 108 inches.

Upon the whole, the experiments on the action of weak organic acid solutions on raw clay sub-soil, did not give results from which any very definite conclusions can be drawn, as to the probability that the action of roots on the soil, by virtue of their acid sap, is quantitatively an important source of the nitrogen of plants having an extended development of roots, of which the sap is strongly acid.

That roots do attack certain mineral substances by virtue of their acid-sap, was established by Sachs. It was to carbonic acid that he attributed the action ; but there seems no reason to suppose that other acids in the root-sap may not exert a similar action. The published results of Sachs and others have, however, reference only to the taking up of mineral substances from the soil by virtue of such an action ; and the possibility or probability that the nitrogen of the soil or sub-soil is so taken up, has, I believe, not been considered.

As bearing on the point, it may be stated that Dr. G. Loges and M.M. Berthelot and André, by extracting rich soils by strong hydrochloric acid, have found that soluble amides are obtained. Supposing the acid root-sap so to act on the insoluble organic nitrogen of the soil, and especially of the sub-soil, the question would still remain—whether the amide rendered soluble is taken up by the plant as such, as seems to be probable in the case of the fungi, or whether it undergoes further change—into ammonia or nitric acid—before serving as food for the plants ?

The first point to consider is, then, whether chlorophyllous plants can take up amide-bodies and assimilate their nitrogen ?

Many vegetation experiments have been made to determine this point. In the case of experiments in which soil was used as a matrix, it seemed probable that the amide-body suffered change before becoming available as a source of nitrogen. In the case of some water-culture experiments, however, it was concluded that the amide-body was taken up by the plant as such, and contributed directly as a source of nitrogen to it. It would seem not improbable, therefore, that they might take up directly, and utilize, amide-bodies rendered soluble within the soil by the action of their acid root-sap.

As a portion of the nitrogen of the soil, when acted upon by acids, is liberated as ammonia, it is a question whether this will be either wholly, or partially, nitrified, before being taken up by the plant. Obviously, too, if the portion brought into the condition of soluble amide, be not taken up as such, it also will be subject to further change ; perhaps first into ammonia, and then into nitric acid. But, on such a supposition,

we should obviously be again met with the difficulties in the way of assuming that the conditions within the sub-soil would be adequate for so much nitrification.

It will be seen, therefore, that although significant indications have been obtained, both as to the importance of nitric acid as a source of the nitrogen of the Leguminosæ, and as to the action of acids in rendering soluble the otherwise insoluble nitrogenous compounds of soils and sub-soils, yet on neither of these points is the evidence at present available, adequate to account satisfactorily for the facts of growth.

It will be of interest, briefly to refer to some evidence relating to another mode in which green-leaved plants may acquire nitrogen from the stores already existing in the combined state, but in an insoluble condition, in the soil and sub-soil.

Thus, Professor Frank has observed that the feeding roots of certain trees are covered with a fungus, the threads of which force themselves between the epidermal cells into the root itself, investing the cell, but not penetrating the fibro-vascular tissue. In such cases the root itself has no hairs; but there are similar bodies external to the fungus-mantle, which are prolonged into threads among the particles of soil. The fungus-mantle dies off on the older portions of the root, and its extension is confined to the younger parts, those which are active in the acquirement of nutriment.

Frank considers that the conditions are those of true symbiosis; and that the chlorophyllous tree acquires the carbon, and the fungus the water and the mineral matters, that is the soil-nutriment. He did not refer to nitrogen, but there seems no reason to suppose that the fungus could not, as do the fungi in the case of fairy rings for example, avail itself of the organic nitrogen of the soil.

Here, then, is a mode of accumulation of soil-nutriment by some green leaved plants, which so far allies them very closely to fungi themselves. Indeed, it is by an action on the soil which characterises *non-chlorophyllous* plants, and by virtue of which they are enabled to take up nutriment not available to most green-leaved plants, that the chlorophyllous plant itself acquires its soil supplies of nutriment. It can readily be supposed that, under such circumstances, the tree may acquire not only water and mineral matter, but both organic carbon, and organic nitrogen, from the soil. In reference to this point it may be stated that, from the evidence so far at command, it was concluded that the action is the most marked in the surface layers of the soil rich in humus.

So far as this is the case, it is obvious that such an action of fungi on the soil does not aid us in the explanation of the acquirement of nitrogen from raw clay sub-soil, by the deep and strong rooted Leguminosæ.

Further, it is distinctly stated, that the fungus development in question has not been observed on the roots of any herbaceous plants. It is, nevertheless, a point of interest, should it be established, that by

special means, in special cases, the organic nitrogen of the soil may contribute to the supply of nitrogen to chlorophyllous plants.

I have now considered in some detail the sources of already combined nitrogen available to our crops; and the evidence points to the conclusion that, independently of the small amount of combined nitrogen annually coming from the atmosphere in rain, and the minor aqueous deposits, the source of the nitrogen, at any rate of most of our crops, is the stores already existing within the soil and sub-soil, or those provided by manure. It has further been seen that the combined nitrogen is largely taken up as nitric acid, or rather as nitrates. But it is nevertheless obvious, that we have yet to seek for an explanation of the source of the whole of the nitrogen of the Leguminosæ in some cases.

We are brought to enquire, therefore, what is the evidence relating to the question of *the fixation of free nitrogen*, by the plant, by the soil, or otherwise?

EVIDENCE AS TO THE FIXATION OF FREE NITROGEN.

Even nearly a century ago, it was a matter of discussion whether plants took up, or evolved, free nitrogen; and it is just about half a century, since Boussingault commenced a series of vegetation experiments to determine whether plants do assimilate the free nitrogen of the atmosphere. From the results then and subsequently obtained, he concluded that they did not; and results obtained at Rothamsted nearly 30 years ago confirmed those of Boussingault. But others came to an opposite conclusion; and a somewhat active controversy was maintained on the subject for some time. Eventually it seemed to be pretty generally admitted, that plants did not directly assimilate the free nitrogen of the air. During the last few years, however, the discussion has assumed a somewhat different aspect.

The question still is, whether the free nitrogen of the air is an important source of the nitrogen of vegetation; but whilst few now adhere to the view that chlorophyllous plants directly assimilate free nitrogen; it is nevertheless assumed to be brought under contribution in various ways—coming into combination within the soil, under the influence of electricity, or of micro-organisms, or of other low forms, and so indirectly serving as an important source of the nitrogen of plants of a higher order.

Several of the investigations in the lines here indicated, seem to have been instigated by the assumption, that natural compensation must be found, for the losses of combined nitrogen which the soil sustains by the removal of crops; and for the losses which result from the liberation of nitrogen from its combinations, under various circumstances.

It was about 1876, that M. Berthelot called in question the legitimacy of the conclusion that plants do not assimilate the free

nitrogen of the air, when drawn from the results of experiments in which the plants were so enclosed as to exclude the possibility of electrical action. More recently, he has objected to experiments so conducted with sterilised materials, on the ground that, under such conditions, the presence, development, and action, of micro-organisms, are excluded.

There is, however, I believe, nothing in the recent results, either of Berthelot or of others, which can be held to invalidate the conclusion, drawn from the results of Boussingault, and from those obtained at Rothamsted about 30 years ago, that the higher plants do not fix the free nitrogen of the atmosphere, under the conditions then adopted, which, it is admitted, were such as to exclude, both electrical action, and the influence of micro-organisms.

I propose now to give a brief account of recently published results and conclusions from experiments for the most part made under such conditions as not to exclude the possibility of the influence of electricity, or of micro-organisms. The first to notice are those of M. Berthelot himself.

M. Berthelot first showed that free nitrogen was fixed by various organic compounds, under the influence of the silent electric discharge, at the ordinary temperature; and he suggested that such actions probably take place in the air during storms, and when the atmosphere is charged with electricity, organic matters absorbing nitrogen and oxygen. He also experimented with currents of much weaker tension, more comparable with those incessantly occurring in the air, and in all cases he found that nitrogen was fixed by the organic substance. The gains were in amount such as would explain the source of the nitrogen which he considers crops must derive from the atmosphere.

Subsequently, he found that free nitrogen was brought into combination by argillaceous soils, when exposed in their natural condition, but not when they were sterilised. He also found gain when the natural soils were enclosed. He considered the results showed that there was gain of nitrogen quite independently of any absorption of combined nitrogen; in fact that there was fixation of free nitrogen due to living organisms. He further considered that such gains, not only serve as compensation for exhaustion by cropping, &c., but explain how originally sterile argillaceous soils eventually become vegetable moulds.

He also made experiments on the fixation of free nitrogen by vegetable earth supporting vegetation; and he found that there was a gain about equally divided between the soil and the plant, the latter having taken it up from the soil, which he considers is the true source of gain.

The results obtained under the influence of the silent discharge in bringing free nitrogen into combination with certain vegetable principles, of course owed their special interest to the inference that thus free nitrogen might be brought into combination within the soil, or within the plant; but M. Berthelot subsequently considered it doubtful

whether the higher plants do bring free nitrogen into combination at all. Quite recently, however, he has made new experiments, from which he concludes that nitrogen is fixed under the influence of electricity, both in the soil with its microbes, but without higher vegetation, and in soil with higher vegetation.

Obviously if there are organic compounds within the soil which have the power of bringing free nitrogen into combination under the influence of electricity, the soil may be the source, and yet the agent may be the feeble electric current. But, so far as it is assumed that free nitrogen is brought into combination in the atmosphere itself, the resulting compounds will be found in the air, and in the aqueous depositions from it; and the limit of the amount of combined nitrogen so available over a given area, in Europe at any rate, is pretty well known.

M. Dehérain sought to determine the actual losses or gains in the field, under the influence of different manures, of different crops, and of different modes of cultivation. Experiments were made with various crops, each of which was grown without manure, and with three different descriptions of manure, applied for a series of years, and then the crop was grown without manure for some years more.

The nitrogen was determined in the soil, before the commencement of the experiments in 1875; in 1878 after three years of manuring and cropping; in 1881 after four years' cropping without further manuring; and in the case of sainfoin followed by mixed grasses, in 1885 also. Lastly, the nitrogen in the crops was only estimated. From these data, the losses or gains of nitrogen by the soil, during the different periods, under the influence of the different manures and crops, were calculated.

With regard to the actual amounts of loss or gain of nitrogen found in M. Dehérain's experiments, the losses especially are extremely large, indeed they were far in excess of anything that has come within our own knowledge and experience, and they were in amount such as reflection must show cannot possibly occur in actual practice.

The question arises—how are such results to be explained? I think there can be little doubt that in the method of taking the samples of soil for analysis, an explanation is to be found; and I have the less hesitation in suggesting this, since we fully admit, that our own early results, obtained under somewhat similar conditions, are quite inapplicable for anything like accurate estimates of nitrogen per acre.

In fact, it may be concluded that, certainly the estimated losses by the surface-soils, and probably also the estimated gains, are higher than can possibly happen in practice; and that the results are due to the samples of soil not being taken in such a way, as to ensure strictly comparable estimates at the different periods. At the same time, there can be no doubt that there would be losses beyond those due to the removal of the crops, under the conditions in which losses were found; that is when the land was under arable culture. Nor can there be any doubt that there would be gains in the surface-soil, when the land was

laid down in sainfoin and mixed grasses ; and M. Dehérain points out the practical significance of such facts.

M. Dehérain concluded that the loss of nitrogen by arable soil, that is by soil that is mechanically worked, is due to the slow combustion of the nitrogenous organic matter of the soil ; the nitrogen being either evolved as free nitrogen, or oxidated into nitric acid and carried down into the sub-soil, or into the drains. As to the gain by the surface-soil, he considers, as is doubtless the case, that part is due to the action of deep-rooted plants, in taking up the nitric acid accumulated in the lower layers, and leaving a nitrogenous residue near the surface ; and that as to the gains not so to be accounted for, it is not yet settled whether they are due to the ammonia of the atmosphere, as supposed by M. Schloësing, or to free nitrogen, as supposed by M. Berthelot.

It may be remarked, that, if the losses in ordinary agriculture were in amount anything like those which M. Dehérain's figures show, even such large gains as are also indicated, would be far from sufficient to compensate them. It would indeed be necessary to seek for other sources of restoration, if our arable surface-soils are not to lose their nitrogen much faster than the evidence at command leads us to suppose is the case in actual practice. That they do, however, slowly suffer reduction in their stock of nitrogen, when there is no restoration from without, there can be no doubt. In other words, in actual practice without restoration from external sources, the losses are not fully compensated.

In conclusion in regard to M. Dehérain's experiments, I may add that he has quite recently reiterated his results and conclusions ; but he does not say anything that appears to us to obviate our objections to his quantitative estimates.

M. Joulie made numerous vegetation experiments in which the soils and the plants were, with certain precautions, exposed to the free air, and in which known amounts of combined nitrogen were supplied. He found very variable, but in some cases very large, gains of nitrogen. He considered that the variations of result were largely due to the varying conditions as to mineral-supply in the different experiments.

M. Joulie concluded that microbes probably play an important part in the fixation of nitrogen. He did not think that his results were favourable to the supposition that the plants themselves effected the fixation. For the present he limits himself to the establishment of the great fact of the fixation of the free nitrogen of the atmosphere, leaving to the future the exact explanation.

It is to be observed that the large gains shown were chiefly with a polygonous plant, Buckwheat, and not with plants of the Leguminous family, which are reputed to be "nitrogen collectors."

To show the practical importance of the fixation of free nitrogen, M. Joulie calculates what would be the gain per hectare according to some of his results. It may be confidently affirmed, however, that such gains as he so estimates, do not take place, either with or without vegetation, in ordinary soils, in ordinary practice.

Dr. B. E. Dietzell made vegetation experiments, in which plants were watered with distilled water, the drainage was returned to the soils, and the pots and their contents were exposed to free air, but protected by a linen roof. A rich garden soil, containing 0·415 per cent. of nitrogen, was used, several different conditions as to manuring were adopted, and Peas and Clover were the subjects of experiment. Thus, the plants were of the Leguminous family; but notwithstanding this, there was, in no case, a gain of nitrogen. In one there was neither gain nor loss, and in all the others there was a loss, in some cases amounting to 15 per cent. of the total nitrogen involved.

That there should be loss with a soil containing 0·415 per cent. of nitrogen, that is about three times as much as most ordinary arable soils, is not at all surprising; and it is seen that, neither from the combined nitrogen of the atmosphere, or that due to other accidental sources, nor from free nitrogen, either directly or indirectly, did these reputed "nitrogen collectors" gain nitrogen to compensate the losses from the rich soil.

Professor Frank also made vegetation experiments in free air. His soil was a humus-sand, containing only 0·0957 per cent. of nitrogen; distilled water was used for watering, and the vessels were deep and narrow cylinders, without any arrangement at the bottom for drainage, or for aëration. In three experiments without a plant, in one with two Lupins, and in one with one Lupin and Incarnate Clover together, there was a loss of nitrogen; whilst in one with three Lupins, and in one with one Lupin, there was a gain. Frank considered it probable that where a loss was indicated with vegetation, there had nevertheless been a gain, but not enough to compensate the loss.

In another experiment, with a soil about 12 times as rich in nitrogen, and many times richer than ordinary arable soils, he found a loss, due mainly to evolution of free nitrogen; and, referring to this result, he says that, if such losses take place in ordinary agriculture, there must be natural compensation.

In the experiments in the deep and narrow vessels, without drainage, and without plants to cause evaporation, movement, and aëration, loss by evolution of free nitrogen is only what would be expected. Such loss would also be expected in the two cases of loss with growth, in both of which there was admittedly decomposing organic matter. It was also to be expected in the very rich soil. But it is doubtful whether, in the two cases of gain with growth, and therefore movement within the soil, and aëration of it, there would be any loss. In none of the experiments with loss, however, were the conditions comparable with those of ordinary soils, under ordinary treatment; and the losses found cannot be taken as any indication of what takes place in ordinary practice. It is probable that, in such practice, the loss by evolution of free nitrogen is much less than is generally assumed in discussions of this subject. Doubtless there is, however, frequently considerable loss by the drainage of nitrates.

Frank considers that, independently of direct evidence against the

supposition that the gains were due to the absorption of combined nitrogen from the atmosphere, an objection to such a view is, that it would not explain the circulation of nitrogen in nature; and his main conclusion is, that there are two actions going on within the soil, one liberating nitrogen, and the other bringing it into combination, the latter favoured by vegetation.

Upon the whole, then, it would seem, that the losses found by Frank may be explained by the special conditions of the experiments themselves; whilst the gains, if not to be accounted for by sources of error incidental to experiments made in free air, can only be explained by fixation in some way.

The most remarkable of the results indicating the fixation of free nitrogen are those of Professor Hellriegel and Dr. Wilfarth. Hellriegel found that whilst plants of the Gramineous, the Chenopodiaceous, the Polygonous, and the Cruciferous families, required combined nitrogen to be supplied within the soil, Papilionaceous plants did not depend on such soil-supplies.

Peas, sown in washed sand with nutritive solutions free from nitrogen, generally failed, but occasionally grew luxuriantly; and root-nodules were always developed coincidently with luxuriance, but not without it. But when to the non-nitrogenous sandy matrix, a few c.c. of the watery extract of a rich soil were added, the luxuriance was always marked, as also was the development of the root-nodules. Lupins, however, failed when treated in the same way, but succeeded when the soil was seeded by a watery extract of a sandy soil where Lupins were growing well, and root-nodules were then abundantly produced.

The amounts of produce recorded seemed to leave no doubt that they contained much more nitrogen than was supplied in the seed; whilst the amount added in the soil-extract was quite immaterial. The negative result with Gramineæ, with Peas under sterilised conditions, or in sand not seeded with rich soil-extract, and with Lupins in sand not seeded, or seeded with the rich soil-extract, and, on the other hand, the positive result with Peas in the seeded sand, and with Lupins when the sand was seeded with an extract from a suitable soil, seemed to exclude the supposition of any other source of gain than the fixation of free nitrogen under the influence of micro-organisms; and Hellriegel was disposed to connect the action with the root-nodules and their contents.

Wilfarth gave the results of a subsequent season's experiments, which fully confirmed those recorded by Hellriegel, both as to the negative result with other plants, and to the positive result with Papilionaceæ. Peas grew luxuriantly when the nitrogen-free soil was seeded with the watery extract from any cultivated soil, but *Serradella* and Lupins, only when seeded with an extract from soil where these plants were growing.

In four experiments with Lupins, nearly 50 times as much dry substance was produced, and nearly 100 times as much nitrogen was assimilated, with, as without, seeding with the soil-extract!

Wilfarth concluded that the Papilionaceæ can derive the whole of their nitrogen from the air, but that it is doubtful whether the root-nodules are connected with the fixation, though the results point to the agency of bacteria in some way.

In reference to these results, whilst it can hardly be said that there is an unsolved problem in regard to the source of the nitrogen of our *non*-Leguminous crops, it must be admitted that, in spite of all the investigations and discussions of the last 50 years, the source of the whole of the nitrogen of our Leguminous crops has not been satisfactorily explained by results obtained on the lines of inquiry until recently adopted. Evidence obtained on new lines should, therefore, receive careful consideration; and there can be no doubt that, in recent years, cumulative evidence has been adduced, indicating that Chlorophyllous plants may avail themselves of nitrogen brought into combination under the influence of lower organisms; the development and action of which would seem in some cases to be a coincident of the growth of the higher plants to be benefited. But such a conclusion is of such fundamental importance, that it seemed desirable it should be confirmed by others. To some results obtained at Rothamsted in this direction, I shall refer further on.

So long ago as 1853, Professor Emil von Wolff obtained 6 times as much dry produce of Clover, grown in an ignited rich meadow soil, as in the same soil in its natural state. Thus, the increased growth, and the increased assimilation of nitrogen, took place in a soil not only nitrogen-free, but sterilised; so that, unless micro-organisms were acquired during growth, the supposition of their influence in fixing free nitrogen would be excluded.

Much more recently, Wolff has made numerous experiments, with Oats, Potatoes, and various Papilionaceæ, in river-sand; in some cases unwashed, and in some washed; in some without manure, in some with purely mineral manure, and in some with nitrate in addition. Accordantly with common experience, there was little increase in the Oats or Potatoes with mineral, but much with nitrogenous manure; and, on the other hand, with the Papilionaceæ there was very marked increase with the mineral manure, and but little more by adding nitrate. In the experiments with Lupins, Beans, and Clover, in unwashed sand, the results indicated gain of nitrogen, beyond that probably due to the nitrogenous impurity in the sand; but with sand-Peas, grown in washed sand, which was assumed to be nitrogen-free, the gains from some external source were unmistakable.

As to the explanation, Wolff does not suppose that free nitrogen is fixed by the plants themselves; nor does he favour the view that it was fixed by the agency of micro-organisms. The plants may take up combined nitrogen from the air by their leaves; but he thinks it more probable that combined nitrogen is absorbed from the air by the soil, and that free nitrogen is fixed within the soil under the influence of porous and alkaline bodies. He admits that it is not explained why Cereals do not benefit by these actions as well as Papilionaceæ; and he

suggests whether the greater evaporation from the leaves of the latter causes greater aëration of the soil.

Here, then, the gain of nitrogen by the Leguminosæ is explained in a very different manner from that assumed by other recent experimenters. It seems, however, that the undoubted fact, that the Gramineæ, and other non-Papilionaceous crops, do not benefit by the actions supposed, excludes the supposition that Wolff's results with Papilionaceæ are to be so explained. It is true that, neither in the growth of the Clover in ignited soil, nor in that of the sand-Peas in the washed sand, were the conditions such as would seem favourable for the presence, development, and agency of micro-organisms. But if, in the experiments in free air, there was no accidental source of combined nitrogen, it would seem that the influence of micro-organisms is at least as probable as that of the actions which Wolff supposes.

Professor Atwater made numerous experiments, both on the germination, and on the growth, of Peas. In eleven out of thirteen experiments on germination, more or less loss of nitrogen was observed. In all but one out of fifteen experiments on vegetation, there was a gain of nitrogen, which was very variable in amount, and sometimes very large. As a general conclusion, he states that, in some of the experiments half or more of the total nitrogen of the plants was acquired from the air.

He considers that germination without loss of nitrogen is the normal process; that loss, whether during germination or growth, is due to decay, and therefore only accessory. Nevertheless, he goes into calculations of some of his own results, showing, by the side of the actual gains, the greater gains supposing there had been a loss of 15 per cent. of nitrogen, and the still greater gains if there had been a loss of 45 per cent., as in an experiment by Boussingault under special conditions. Further, he says that whilst actually observed gains are proof of the acquisition of nitrogen, the failure to show gain only proves non-fixation, if it be proved that there was no liberation. He suggests that the negative results obtained by Boussingault and at Rothamsted, may be accounted for by liberation; though at the same time he recognises that the conditions of the experiments excluded the action of either electricity or microbes. It may be remarked that, in the experiments both of Boussingault and at Rothamsted, any cases of decay were carefully observed, and the losses found explained accordingly; and it may be confidently asserted that the conclusions drawn were not vitiated by any such loss.

Atwater concludes that his results do not settle whether the nitrogen gained was acquired as free or combined nitrogen, by the foliage, or by the soil. He considers, however, that, in his experiments, the conditions were not favourable for the action either of electricity or of micro-organisms; and he favours the assumption that the plants themselves were the agents. Lastly, he considers the fact of the acquisition of free nitrogen in some way to be well established; and that thus facts of vegetable production are explained, which

otherwise remain unexplained. To this, and other points involved, I shall refer again presently.

Lastly, I have to summarise those of the results and conclusions of Boussingault, which bear upon the present aspect of the question of the sources of the nitrogen of vegetation. In his earlier experiments, as in those at Rothamsted, sterilised materials had been used as soils; but in 1858 he commenced a series in which more or less of a rich garden-soil was mixed with sand and quartz. In some cases the plants were grown in free air, and in others in closed vessels with confined air. In several cases there was more or less gain of nitrogen; but the greatest gain was in an experiment with a Lupin grown in a closed vessel. Boussingault points out that it was the soil and not the plant that had fixed the nitrogen. The result was so marked that he repeated the experiment in 1859, when he obtained almost identically the same amount of gain as in 1858. He also put 120 grams of the rich soil into a shallow dish, moistened it with distilled water, and exposed it to the air as an experiment on Fallow. The results showed a small gain of nitrogen.

Boussingault further found, that mycodermic vegetation went on in rich soil, and he considered the gains of organic nitrogen represented the remains of such vegetation; whilst the Fallow experiment indicated that the experimental plants had little to do with the action. His general conclusion was, that from the numerical results it must be believed, that the soil had fixed nitrogen; and he considered that, if there were no absolute proof, there was strong presumption, that the nitrogen of the air takes part in nitrification.

In the next year, 1860, he put into one large glass balloon a mixture of rich soil and sand, and into another a similar mixture, with cellulose in addition; each was moistened with distilled water, and the vessels were then closed up for 11 years. During this period, without cellulose rather more, and with cellulose rather less, than one-third of the nitrogen of the soil was nitrified; but in neither case was there any gain of total combined nitrogen. There was, indeed, in both cases, a slight loss of nitrogen indicated. Boussingault concluded that free nitrogen had not contributed to the formation of nitric acid.

The later results of Boussingault did not, therefore, confirm those he obtained in 1858 and 1859; and in answer to a letter from me he wrote in 1876, that he was not aware of any irreproachable observation which established the reality of the fixation of free nitrogen by the soil. He further stated his belief, that neither the higher plants, nor mycoderms, nor fungi (champignons), fix free nitrogen. He also maintained the same view in conversation in 1883.

SUMMARY AND GENERAL CONSIDERATIONS ON THE SOURCES OF THE NITROGEN OF OUR CROPS.

It did indeed seem that, in Boussingault's results of 1858 and 1859, there was *the germ of the germ theory* of the fixation of free

nitrogen, if such took place at all in connection with vegetation. But his own very distinct final conclusion against the supposition of such fixation by the agency of the lower organisms, seemed to indicate the necessity for caution in accepting much of the evidence which has been accumulating during the last few years.

It is evident that since experimenting with non-sterilised materials, and in free air instead of in closed vessels, has become more general, there has been a great accession of evidence which is held to show the fixation of free nitrogen. But, not only are the gains in some cases very small, and in others very large, but the modes of explanation are very different.

Thus, the various modes of explanation of the observed gains of nitrogen are:—that *combined* nitrogen has been absorbed from the air, either by the soil or by the plant; that there has been fixation of *free* nitrogen within the soil, by the agency of porous and alkaline bodies; that there has been fixation by the plant itself; that there has been fixation within the soil (or by the plant), by the agency of electricity; and finally, that there has been fixation under the influence of lower organisms, either within the soil itself, or in symbiotic growth with the higher plant.

The balance of the evidence recorded, is undoubtedly much in favour of the last mentioned mode of explanation. But of all the recent results bearing upon the subject, those of Hellriegel and Wilfarth, with certain leguminous plants, seem to be by far the most definite and significant. Accordingly, as we stated in October, 1888, in a postscript to our paper—“*On the Present Position of the Question of the Sources of the Nitrogen of Vegetation.*” (*Phil. Trans.*, 1889.)—it had been decided to institute somewhat similar experiments at Rothamsted. A preliminary series was, in fact, then in progress; and a more extended one has been undertaken in the present season, 1889. The results of these experiments show conclusively that, by the addition to the experimental soil, of a small quantity of the watery extract of a soil containing the appropriate organisms, there was greatly increased growth, and considerable gain of nitrogen; and there was, coincidentally, a considerable development of the so-called leguminous nodules on the roots of the plants.

The conclusion is, not that the leguminous plant had directly utilised free nitrogen; but that the gain was due to the fixation of nitrogen in the growth of the lower organisms in the root-nodules; the nitrogenous compounds so produced, being taken up and utilised by the leguminous plant. It would seem, therefore, that in the growth of leguminous crops, such as Clover, Vetches, Peas, Beans, Lucerne, &c., at any rate some of the large amount of nitrogen which they contain, and of the large amount which they frequently leave as nitrogenous residue in the soil for future crops, may be due to atmospheric nitrogen so derived. It has yet to be ascertained, however, under what conditions a greater or less proportion of the total nitrogen of the crop will be derived, on the one hand from nitrogen compounds within the soil, and on the

other from such fixation. The probability seems to be, that the proportion due to fixation will be the less in the richer soils, and the greater in soils that are poor in combined nitrogen, and which are open and porous.

Even assuming that, in the case of leguminous crops, there will generally be some gain of nitrogen due to the symbiotic growth supposed, it will nevertheless be well to consider the facts of agricultural production, in their bearing on the question of the sources of the nitrogen of crops generally.

As already said, much of the investigation that has been undertaken in recent years, has been instigated by the assumption that there must exist natural compensation for the losses of combined nitrogen which the soil suffers by the removal of crops, and for the losses which result from the liberation of free nitrogen from its combinations under various circumstances. In some cases, however, the object seems to have been for the most part limited to an attempt to solve the admitted difficulty as to the explanation of the source of the whole of the nitrogen of the Leguminosæ.

As to the losses which the soil sustains by the removal of crops, Berthelot, for example, assumes that 50 to 60 kilog. of nitrogen will be annually removed from a hectare of meadow (= 45 to 54 lbs. per acre); and that, as only 10 kilog., or less, of this will be restored as combined nitrogen in rain, &c., there will be an annual loss of from 40 to 50 kilog. per hectare (= 36 to 45 lbs. per acre); so that, if there were not compensation from the free nitrogen of the air, the soil would become gradually exhausted. Further, he considers that the fact of the fixation of free nitrogen, not only explains how fertility is maintained, but how argillaceous soils, which are sterile when first brought into contact with the air, gradually yield better crops, and at length become vegetable moulds. Frank, again, assumes that the average loss of nitrogen by the removal of crops is 51 kilog. per hectare (= 45 lbs. per acre).

It is quite true, that a good hay crop may contain as much as 50 to 60 kilog. of nitrogen per hectare; but it may safely be affirmed that, in ordinary practice, even in the case of an unusually fertile meadow, such an amount is not annually removed for a number of years in succession, without the periodical return of manure supplying nitrogen; whilst, taking the average of soils, the annual yield will seldom reach the amount supposed, even with the ordinary periodic return, and without such return gradual exhaustion would be very marked. Indeed, it is well known that there is no more exhausting practice than the annual removal of hay without return of manure; so that, in point of fact, restoration in anything like the degree supposed, certainly does not take place. Next to the removal of hay, the consumption of the grass for the production of milk is the most, but still very much less, nitrogen-exhausting; whilst, if grass be consumed by store or fattening animals, the loss is very much less still; indeed, it is then very small.

Obviously, however, it is more important to consider, what is the probable average loss of nitrogen over a given area by the removal of crops generally, and not by that of grass alone. Moreover, in making such an estimate, it is not the total nitrogen of the crops that has to be reckoned; but, taking into account the return by manure, only the amount eventually lost to the soil. With the great variation according to circumstances, it is of course very difficult to estimate this at all accurately; but it may be stated, that two independent modes of estimate lead to the conclusion that, for Great Britain for example, the average annual loss of nitrogen is more probably under than over 20 lbs. per acre (= 22.4 kilog. per hectare). In fact, the loss by cropping under the usual conditions of more or less full periodical return by manure, is by no means so great as is generally assumed in discussions of this subject.

The loss of nitrates by drainage may, however, in some cases be considerable. There may also, under some circumstances, be loss by the evolution of free nitrogen. Such loss may take place in the manure heap; or in soils very heavily manured, as in market gardening, for example. But in ordinary agriculture such excessive manuring seldom takes place; and the soil is generally much poorer in nitrogen than in the cases of the experiments which have been adduced as showing great loss from rich soils. Loss may also take place when the soil is deficiently aerated; but, here again, the conditions of the experiments cited, in which considerable loss by evolution of free nitrogen was observed, are not the usual conditions of soils in actual practice. Indeed, the balance of evidence is against the supposition that there is a constant and considerable loss by the evolution of free nitrogen from arable soils which are only moderately rich in organic nitrogen, and which are fairly drained, either naturally or artificially.

On this point it may be mentioned that, in those of the field experiments at Rothamsted in which the unusual practice of applying farm-yard manure every year is adopted, it is found that there is considerable loss of nitrogen from the soil, beyond that known to be removed in the crops, and estimated to be lost in the drainage.

On the other hand, where no nitrogen has been applied for many years, and the amount of nitrogen in the surface soil is only about, or little more than 0.1 per cent., the loss of nitrogen by the soil over a long series of years corresponded approximately with the amounts removed in the crops, together with those estimated to be lost in the drainage. Again, when ammonium-salts are applied, even so late in the season as October or November, and drainage takes place soon afterwards, the drainage-waters will contain amounts of nitrogen showing a very direct relation to the different amounts of ammonia applied in the manure; but scarcely any of it as ammonia, nearly the whole existing as nitric acid; and this is the case although the drainage passes through twenty inches or more of raw clay sub-soil. Lastly, direct experiments have shown that there is a diminution in the amount of nitric acid in the soil down to a certain depth, varying according to the

root-range of the crop grown, and to the season, but that in the depths of the sub-soil below this point, the amount is again greater.

Again, M. Berthelot thinks it probable, though not absolutely established, that there is loss of nitrogen from the plant itself during growth. Long ago, we supposed that there was such loss; but careful consideration of the evidence relating to the subject has led us to the conclusion that it is not proved, and to believe that it probably does not take place. It may be observed, that when in his vegetation experiments M. Boussingault found a loss of nitrogen, there was coincidently some decaying vegetable matter, such as fallen leaves; and in somewhat parallel experiments at Rothamsted, no loss of nitrogen was found as a coincident of growth, and in the absence of dead vegetable matter. Indeed, if there were such loss during growth when there was no decay, either in M. Boussingault's experiments or our own, it must have been almost exactly balanced by corresponding gain; an assumption which is without any proof, but which has nevertheless had its advocates.

In fact it may be concluded that, under the existing conditions of practical agriculture in temperate climates, the annual loss of combined nitrogen over a given area, by cropping and otherwise, is by no means so great as has been assumed; that the restoration required to compensate the loss is, therefore, correspondingly less; and further, that the known facts relating to the maintenance or the reduction of the fertility of soils, do not point to the conclusion that such loss as actually does take place, is compensated by such restoration.

The well known accumulation of nitrogen which takes place in the surface-soil within a few years, when arable land is laid down to grass, is, it may be admitted, not conclusively explained. At the same time, there is abundant experimental evidence pointing to the conclusion that some deep-rooted leguminous plants derive a considerable quantity of nitrogen from the sub-soil; and there seems no reason to doubt that the deep-rooting plants of the mixed herbage of grass-land, whether leguminous or otherwise, may also avail themselves of sub-soil nitrogen; and, if so, it is to be supposed that they, like clover for example, will leave nitrogenous crop-residue in the surface-soil, the nitrogen of which has been derived from the sub-soil. In reference to this point it may be observed, that at Rothamsted there is per acre, in soil and sub-soil, to the depth at which the action of some deep-rooted, and large nitrogen-accumulating plants, has been proved, a store of about 20,000 lbs. of already combined nitrogen. It is true that whilst many other soils and sub-soils will contain as much, or more, many will contain much less.

It is indeed pretty certain, that at any rate much of the nitrogen gained by the surface-soil of land newly laid down to grass, has its source in the combined nitrogen of the sub-soil. Obviously, however, in view of results showing that leguminous crops may acquire nitrogen brought into combination under the influence of the symbiotic growth of lower organisms, the question suggests itself whether part of the

nitrogen accumulated in the surface-soil of land laid down to grass may not be due to such an action. On this point it may be remarked, that the "*nodules*" have been observed on the roots of some Leguminosæ growing in the mixed herbage of grass-land. On the other hand, it has to be borne in mind, that the proportion of leguminous plants in such mixed herbage is comparatively small. Further, it has yet to be determined whether the source of the nitrogen of the bacteroids in the nodules is exclusively free nitrogen, when the development proceeds in soil and sub-soil containing a large amount of combined nitrogen.

As to the supposition that the gains of nitrogen in argillaceous matters of very low initial nitrogen-contents, and which are attributed to the fixation of free nitrogen, serve to explain the gradual formation of vegetable soils, there cannot be any doubt that, so far as nitrogen is concerned, the natural fertility of most soils is at any rate mainly due to the accumulation of ages of natural vegetation, with little or no removal of it, by animals or otherwise; and if the amounts of nitrogen even now brought into combination over a given area under the influence of electricity in equatorial regions, were not exceeded in the earlier periods of the history of our globe, that would probably be sufficient, with growth and with little or no removal, through the ages which modern science teaches us to reckon upon, to account for most, if not the whole, of the accumulations in natural grass, or forest lands; and it is these which have to a great extent furnished us with our meadows and pastures, and arable soils.

Frequently the natural forests have been on the more elevated, or the more undulating lands, and the soils they have formed are less rich than the prairie lands for the most part found in the valleys or on the plains. Taking the vast areas of fertile natural prairie on the American continent for example, sometimes of several feet in depth, it may be estimated that, in such cases, each foot of depth will contain from 6,000 to 10,000 lbs., or even more, of combined nitrogen per acre; and the probable time of these accumulations at any rate obviates the necessity of assuming the intervention of the free nitrogen of the atmosphere, brought into combination by the soil, or by the plants themselves. So far, however, as leguminous growth may have contributed to the result, it is, in view of existing evidence, to be supposed that some at any rate of the accumulation may have been due to fixation under the influence of the symbiotic growth of lower organisms and the higher plants.

Further, the history of agriculture so far as it is known, indicates that arable soils without supplies by manure from external sources, do, as a matter of fact, gradually become less fertile. This, as a rule will take place more rapidly in undulating or high forest lands, than in the natural grass or prairie lands of the plains.

Again, if we compare the amount of nitrogen in the surface-soil of permanent grass land, with that of adjoining land of the same original character, but which has for some time been under arable culture, we find that the latter is much poorer in nitrogen. In illustration, it may

be stated, that whilst the surface-soil of the grass land at Rothamsted contains from 0·25 to 0·30 per cent. of nitrogen, that of the corresponding arable land contains only from 0·1 to 0·15 per cent. The arable soil has, in fact, originally been covered with natural vegetation of some kind, with comparatively little removal, and consequent accumulation; whilst, under arable culture, much of the accumulated nitrogen has been used up, and the loss has not been compensated by free nitrogen brought into combination within the soil, either under the influence of electricity or of lower organisms. Indeed, whether or not there is any restoration of the kind supposed, a consideration of the origin of soils generally, and of the history of agriculture in different countries, leads to the conclusion that the losses of combined nitrogen by cropping, and in other ways, are not compensated by corresponding amounts of free nitrogen constantly brought into combination.

The Rothamsted Field Experiments have now been continued long enough to afford some pertinent examples bearing upon this subject.

Thus, in the case of the plots under continuous wheat, continuous barley, alternate wheat and fallow, and continuous root-crops, with mineral, but without nitrogenous manure, the average annual yield of nitrogen in the crops, has only been about or under 20lbs per acre; the amount has declined to less than the average in the later years; and, coincidently with the continuous and diminishing growth, the percentage of nitrogen in the surface-soil has been considerably reduced. The loss by the removal of even such small crops, together with that by drainage, has, therefore, as a matter of fact, not been compensated by free nitrogen brought into combination, either by the plants, or within the soil.

In the field where the Leguminous crop—Beans, had been grown 25 years out of 32, with mineral but without nitrogenous manure, and had yielded less than average agricultural crops, the per-centage of nitrogen in the surface-soil was also greatly reduced.

In another field, where the Leguminous crop—Red Clover, had been sown 12 times in 30 years, the Clover failed many times, the yield of nitrogen in the crops very greatly diminished, and the per-centage of nitrogen in the surface-soil was greatly reduced.

Again, in rich garden-soil, where Red Clover has been grown for 36 years consecutively, and has yielded throughout good, but gradually diminishing crops, it was found, after the first 22 years, that the nitrogen in the surface-soil had been reduced from 0·5095 to 0·3634 per cent., or by about one-third.

Even in an actual course of rotation, of Turnips, Barley, Clover or Beans, and Wheat, with mineral, but without nitrogenous manure, the per-centage of nitrogen in the surface-soil has been much reduced; whilst, in a parallel rotation in which Fallow takes the place of the Clover or Beans, the reduction is still greater.

Thus, in all the cases cited, including Gramineous, Cruciferous, Chenopodiaceous, and even Leguminous crops, and a rotation of crops, grown for many years in succession without nitrogenous manure, and yielding

comparatively small and declining amounts of nitrogen in the produce, there has, coincidentally, been a considerable reduction in the amount of nitrogen in the surface-soil. There has, in fact, not been compensation from the free nitrogen of the air, or at any rate not at all in amount corresponding to the annual losses.

Lastly, Grass-land which, under the influence of a full mineral manure, including potash, but without any supply of nitrogen for more than thirty years, has grown crops containing rather large amounts of comparatively superficially rooting leguminous herbage, which has been succeeded by increased amounts of gramineous herbage, and has, under those conditions, yielded about the same amount of nitrogen per acre as M. Berthelot assumes to be the average produce of a meadow, but it has done so, only with coincident great reduction in the nitrogen of the surface-soil.

Whether, therefore, we consider the facts of agriculture generally, or confine attention to special cases under known experimental conditions, the evidence does not favour the supposition that a balance is maintained by the restoration of nitrogen from the large store of it existing in the free state in the atmosphere. Further, our original soil-supplies of nitrogen are, as a rule, due to the accumulations by natural vegetation, with little or no removal, over long periods of time. Or, as in the case of many deep subsoils, the nitrogen is partly due to animal remains, intermixed with the mineral deposits. The agricultural production of the present age is, in fact, so far as its nitrogen is concerned, largely dependent on previous accumulations; and, as in the case of the use of coal for fuel, there is not coincident and corresponding restoration, so in that of the use or waste of the combined nitrogen of the soil, there is not evidence of coincident and corresponding restoration of nitrogen from the free to the combined state.

In the case of agricultural production for sale, without restoration by manure from external sources, a very important condition of the maintenance of the amount of nitrogen in the surface-soil, or of the diminished exhaustion of it, is the growth of plants of various range and character of roots, and especially of leguminous crops. Such plants, by their crop-residue, enrich the surface-soil in nitrogen. It is, as a rule, those of the most powerful root-development that take up the most nitrogen from somewhere; and this fact points to a sub-soil source. But, independently of this, which obviously may be held to be only evidence of the necessity of obtaining water and mineral matters from below, in amount commensurate with the capability of acquiring nitrogen, direct experimental evidence can leave no doubt that such plants do obtain at any rate much of their nitrogen from the sub-soil. The question arises—whether or not the whole of the nitrogen of our crops comes from combined nitrogen, in the soil and sub-soil, in manure, and in rain, &c., or whether part of it is in some way derived from the free nitrogen of the atmosphere? Cumulative evidence points to the conclusion that, in the case of our gramineous, our cruciferous, our chenopodiaceous, and our solaneous crops, free nitrogen is not the

source. Recently acquired evidence indicates, however, that it may, indirectly, be the source of at any rate some of the nitrogen of Leguminosæ. It would further seem, that the development of the organisms capable of bringing free nitrogen into combination, if not an essential coincident of the growth of some leguminous plants, is at any rate favoured by such growth.

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