XLIV.—*On some Points in the Composition of Soils; with Results Illustrating the Sources of the Fertility of Manitoba Prairie Soils.**

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THIS paper may be considered as a continuation of one read in the Chemical Section, at the meeting of the American Association for the Advancement of Science held at Montreal, in August, 1882, entitled—"Determinations of Nitrogen in the Soils of some of the Experimental Fields at Rothamsted, and the Bearing of the Results on the Question of the Sources of the Nitrogen of our Crops,"—and in order adequately to bring out the bearings of the new results, embodied in the present communication, it is desirable, first to summarise the main results and conclusions of the previous one.

The question of the sources of the nitrogen of our crops is one respecting which very conflicting views are still entertained; and it may at once be admitted that so long as the facts of agricultural production alone are studied, without knowledge of, or reference to, the changes in the stock of nitrogen in the soil, it would seem not unreasonable to assume that a large proportion of the nitrogen, at any rate of some crops, must be derived, in some way or other, from the atmosphere.

Yield of Nitrogen per Acre in Different Crops.

Obviously, it is a point of first importance to determine what really is the annual yield of nitrogen in different crops over a given area, excluding, as far as possible, the amounts due to unknown supplies by manure; thus, as far as practicable, limiting the source to the stores of the soil itself, and to the atmosphere. The Rothamsted field experiments, in which different crops have been grown for very many years in succession on the same land, both without nitrogenous manure, and with known quantities of such manure, afford valuable data of the kind required; and, in our former paper, the results were discussed in some detail. It must suffice here to summarise them very briefly.

The average yield of nitrogen per acre per annum was, in wheat, 32 years without manure 20·7 lbs., and 24 years with a complex

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mineral manure 22·1 lbs.; in barley, 24 years without manure 18·3 lbs., and 24 years with a complex mineral manure 22·4 lbs.; in root-crops, 36 years (including 3 of barley), with a complex mineral manure 25·2 lbs.; in beans, 24 years without manure 31·3 lbs., and 24 years with a complex mineral manure 45·5 lbs.; in clover, 6 crops in 22 years, with 1 of wheat, 3 of barley, and 12 years of fallow, without manure 30·5 lbs., and with a complex mineral manure 39·8 lbs.; in clover on land which had not grown the crop for many years, 1 year 151·3 lbs.; in a rotation of crops, 7 courses, 28 years, without manure 36·8 lbs., and with superphosphate of lime 45·2 lbs.; in the mixed herbage of grass land, 20 years without manure 33 lbs., and with complex mineral manure, including potass, 55·6 lbs.; lastly, with Bokhara clover, 5 years, with mineral manure, 92 lbs. of nitrogen, per acre per annum.

Thus, the annual yield of nitrogen per acre, none being supplied in manure, was the least in the cereal crops, more in the root-crops, and much more still in the leguminous crops, whilst in a rotation of crops, in which roots and Leguminosæ were interpolated with cereals, the annual yield of nitrogen was very much greater than in cereals grown year after year on the same land.

But, an essential point to remark is, that in all the experiments on arable land, whether with cereal crops, root-crops, leguminous crops, or a rotation of crops, grown without nitrogenous manure, *the decline in the annual yield of nitrogen was very great;* and this was the case even when a full mineral manure was applied. Even with the deep-rooted *Melilotus leucantha* the crops of the sixth and seventh years show a considerable decline in yield.

The Sources of the Nitrogen of Crops.

The next question is—what are the possible sources, other than the soil itself, of the amounts of nitrogen annually yielded in crops over a given area, when none is supplied by manure? This part of the subject was considered in some detail in our former paper, as it has been on previous occasions. It is only necessary here to state very briefly the general results of these former inquiries.

1. *Combined Nitrogen in Rain, &c.*

In Liebig's earlier writings, he assumed the probability of a very much larger quantity of ammonia coming down in rain than he did subsequently, but even in his *Natural Laws of Husbandry*, published in 1863, he concluded that as much as 24 lbs. of nitrogen per acre may be annually available to vegetation from that source. It is obvious that such an amount would do much towards meeting the requirements of many of the crops the yield of nitrogen in which has been given above.

In 1852, Boussingault determined the amounts of ammonia in the rain collected in Alsace during a period of nearly six months. His average amount of ammonia per million of rain was somewhat less than that found at Rothamsted in 1853, 4, 5, and 6; with approximately the same annual rainfall in the two localities. The amount of combined nitrogen found in the Rothamsted rain at that time corresponded to a deposit of about 6 lbs. as ammonia, and about $\frac{3}{4}$ lb. as nitric acid, per acre per annum; or in all less than 7 lbs.; whilst more recent determinations made at Rothamsted lead to the conclusion that the total amount of combined nitrogen contributed in the rain and the minor measured aqueous deposits probably does not exceed 5 lbs. per acre per annum; including that as ammonia, as nitric acid, and in organic matter.

Determinations of ammonia and nitric acid in the rain of numerous localities on the continent of Europe have been made, and the mean result for nine places, some urban and some country, and representing in all the collection of 22 yearly periods, corresponds to an average annual supply of about $10\frac{1}{4}$ lbs. of combined nitrogen per acre per annum.

Upon the whole, therefore, we are disposed to conclude that the supply of combined nitrogen coming down in the measured aqueous deposits from the atmosphere, little, if at all, exceeds 5 lbs. per acre per annum, in the open country, in Western Europe.

With records of the amounts contributed in rain and the minor aqueous deposits, we come to an end of all quantitative evidence as to the amounts of combined nitrogen available to the vegetation of a given area from atmospheric sources; and it will be seen that the amount so available is very far from adequate to supply the quantities annually yielded in different crops grown without nitrogenous manure.

It is true that the minor aqueous deposits from the atmosphere are much richer in combined nitrogen than rain; and there can be no doubt that there would be more deposited within the pores of a given area of soil than on an equal area of the non-porous even surface of a rain-gauge. There is, however, no evidence enabling us to estimate how much may be available from this source, in addition to that determined in the collected aqueous deposits. The quantity will doubtless vary according to the character, and to the temporary mechanical condition, of the soil; and the quantity absorbed and retained may be influenced by the character of the vegetation with which the land is covered. Still, such as it is, the evidence at command bearing on the point, leads to the conclusion that the amounts so available are but small, and quite inadequate to make up the deficiency between the amounts supplied directly in rain, and those yielded in the crops grown without nitrogenous manure.

Other Supposed Sources of Combined Nitrogen.

Among other possible supplies of combined nitrogen to the soil from atmospheric sources, it has been supposed that, in the last stages of the decomposition of organic matter in the soil, hydrogen is evolved, and that this nascent hydrogen combines with the free nitrogen of the atmosphere, and so forms ammonia; or that in the oxidation of organic matter in the soil, there may be an evolution of ozone, which, combining with free nitrogen, forms nitric acid.

We have on former occasions given reasons for concluding that these supposed sources cannot be taken as accounting for the facts of growth. Indeed, such evidence as exists on the point, even supposing these actions take place at all, leads to the conclusion that any amounts of combined nitrogen so available must, like those due to direct condensation by the porous soil, be both limited and inadequate.

But if the supplies from the atmosphere to the soil are inadequate, may not there be direct supply from the atmosphere to the plant itself?

Here again, the conclusion arrived at, after careful consideration of the evidence available was, that even broad-leaved plants, such as the root-crops for example, which have been assumed to absorb a considerable quantity of ammonia from the atmosphere by their leaves, do not derive any material amount of their nitrogen in that way.

Lastly, comes the question whether plants assimilate the free nitrogen of the atmosphere, and whether some descriptions do so in a much greater degree than others.

On this point there is a great deal of experimental evidence at command; but the results are very conflicting, and we have concluded that the balance of the evidence is decidedly against the supposition that plants do assimilate the free nitrogen of the atmosphere.

To recapitulate: the amounts of combined nitrogen annually coming down in the measured aqueous deposits from the atmosphere in the open country are quite inadequate to supply more than a small proportion of the nitrogen assimilated by crops over a given area, when none is supplied by manure. With regard to other possible supplies of combined nitrogen to the soil, there is no direct quantitative evidence at command, but such evidence as does exist points to the conclusion that such supplies are at any rate very limited and inadequate. The same may be said of the supposed combination of the free nitrogen of the air within the soil; also of the supposition that plants take up any material proportion of their nitrogen from combined nitrogen in the atmosphere by their leaves. Finally, the balance of direct experimental evidence is against the supposition that plants assimilate the free nitrogen of the atmosphere.

The Nitrogen of the Soil as a Source of the Nitrogen of Crops.

The special object of our former paper, as indicated by its title, was to record and discuss determinations of nitrogen in the soils of some of the experimental fields at Rothamsted, and to show the bearing of the results on the question of the sources of the nitrogen of the crops grown.

When it is borne in mind that a difference in the amount of nitrogen in the soil of 0·001 per cent. may represent a difference of 20 to 25 lbs. per acre in a layer 9 inches deep, it will be seen how difficult it is to obtain results which are applicable for estimating the loss or gain of the soil from one period to another. In our former paper, these difficulties were considered in some detail, and the methods of collecting and preparing samples of soils for analysis were described.

Further, it was concluded that, owing to the low actual percentage of nitrogen in subsoils, and to the proportionally great variation in the percentage in different samples taken from the same plot and to the same depth, obviously due to natural inequalities, and unconnected with the special history of the plot, it was in most cases misleading to attempt to estimate changes in the stock of the total nitrogen of the soil beyond a comparatively limited depth from the surface—in fact very little beyond the depth to which the soil is influenced by the mechanical operations in the case of arable land, and by active root-development in that of grass land. Accordingly, most of our calculations of *total nitrogen* in the soil have been limited to that in the first 9 inches of depth.

Although the results of the determination of *total nitrogen* in the subsoils of different plots are thus inapplicable for the calculation of the loss or gain of the soil to any considerable depth, yet the determinations of the amounts of nitrogen existing as nitric acid—that is, of nitrogen in a soluble, and, so to speak, migratory condition—in the subsoils of plots in different conditions, induced by cropping or manuring, have much significance. It is a special object of the present paper to bring forward the results of new determinations of nitrogen as nitric acid, in soils and subsoils of known history, in some cases to the depth of twelve times 9 inches, or in all to 108 inches.

In order that the bearing of these new results on the question of the sources of the nitrogen of our crops may be better understood, it is desirable first to summarise the results and conclusions of our former paper, both as to the amount of total nitrogen, and the amounts of nitrogen as nitric acid, found in various soils.

The Experimental Wheat-field Soils.—In the case of the field in which wheat has now been grown year after year from 1844 up to the present time, samples of the soils of many of the plots were taken in 1865, after 22 crops had been removed, and again in 1881, when 16 more had been taken. In these samples, the nitrogen was determined by the soda-lime method, and in some of them the nitrogen as nitric acid also.

It has been stated that on the continuous wheat-plot without any manure, and on that with mineral, but without nitrogenous manure, there was a marked decline in the annual yield of nitrogen per acre in the crops. The determinations of nitrogen in the soils showed that, with this decline of yield in the crops, there was also a marked reduction in the stock of nitrogen in the soils.

Calculation further indicated that the soil had lost nitrogen in amount corresponding to about two-thirds the quantity removed in the crops and lost by drainage. The conclusion was, that the soil itself had contributed, at any rate the greater part of the nitrogen annually removed in the crop and lost by drainage. The combined nitrogen in the rain and minor aqueous deposits, together with that in the seed sown, would supply most of the remainder. Thus there was very little to be provided from all the other possible sources taken together.

The Experimental Barley-field Soils.—From some of the plots in the field which has grown barley every year from 1852 up to the present time, samples of soil were taken in 1868, and again in 1882. Between these dates 13 barley crops had been removed. On the plot which had received a complex mineral manure every year, but no nitrogen, the records of average annual yield of nitrogen in the crops showed a gradual decline over the later years; and the nitrogen determinations in the soils showed, as in the case of the wheat soils, a reduction in the stock of nitrogen in the first 9 inches of depth.

The Experimental Root-crop Soils.—With the exception of 3 years (1853, 4 and 5), when barley was taken without manure, roots have been grown on the same land from 1843 up to the present time. Samples of the soil were taken in 1870 only; but then from 35 different plots. Having only taken samples once, the condition of the land at different periods cannot be compared. But, in the case of 4 plots, one entirely unmanured, and 3 with purely mineral manure, every year, the percentage of nitrogen in the first 9 inches of depth was at that time, that is, after 27 years of experiment, found to be lower than in any other of the experimental fields; though determinations made in samples from other parts of the same field, and also from an adjoining field, show much higher results.

Now, the yield of nitrogen in the root-crops was, in the earlier years, much higher than, and in the later as low as, in the case of the cereals; and it is quite consistent with the conditions of soil known to be favourable for the growth of root-crops, and with the amount of fibrous root they throw out near the surface, that their growth should lead to a greater reduction in the stores of nitrogen of the superficial layers than in the case of other crops. In fact, the conclusion is, that the dependence of root-crops for their nitrogen on the stores of the soil itself, or on supplies by manure, is as clearly established as in the case of the cereals.

The Nitrogen of the Leguminosæ.

It has been shown that the leguminous crops yield much more nitrogen per acre than either cereals or root-crops, but that when grown continuously without nitrogenous manure, they, like the other crops, decline in annual yield.

The Experimental Bean-field Soils.—These experiments were commenced in 1847, and continued with some breaks until 1878. Without manure, the yield of nitrogen was in the earlier years much higher than in the cereals; but it declined very much, and in the later years it was as low as in the cereals. With mixed mineral manure, including potash, the yield was throughout much higher, but still the decline was very great. In 1857, and in 1865, samples of the soils of some of the plots were taken, and in 1883 of a greater number. Confining attention to the unmanured and mineral manured plots, that is to the plots to which no nitrogenous manure has been supplied, the soils show a very distinct reduction in total nitrogen in the first 9 inches of soil.

The Experimental Clover-land Soils.—An attempt was made to grow clover many years in succession on the same land, the experiment commencing in 1849, and ending in 1877, that is, extending over a period of 29 years. In the early years, some good crops were obtained, and small cuttings at intervals afterwards; but the plant very frequently died off in the winter and spring succeeding the sowing of the seed, so that only 8 years have yielded clover. In 1 year wheat, and in 5 barley, was taken; and in 12 years the land remained fallow.

Notwithstanding that so few crops of clover were produced, that 6 grain crops were grown, and that the land was many years practically fallow, the effect of the interpolation of the clover was to increase the average annual removal of nitrogen from the land considerably beyond that obtained in cereals grown continuously.

In 1881, samples were taken from the clover plots in 5 places, where no nitrogen had been applied; and determinations of nitrogen in them showed nearly as low a percentage in the first 9 inches of depth, as in the soil of an adjoining plot which had been 30 years under alternate wheat and fallow without any manure, and as in the soil of the exhausted root-crop land.

It is significant that, after good crops of clover in the early years, when the land was in ordinary condition, but constant failure afterwards, the percentage of nitrogen in the surface soil should be nearly as low as with alternate wheat and fallow without manure.

In an immediately adjoining field, after 6 grain crops had been grown in succession by artificial manure, the land was divided, and, in 1873, on one half clover (sown in the spring of the previous year), and on the other half barley, was grown. In the clover crops 151·3 lbs., and in the barley only 37·3 lbs. of nitrogen were removed; yet, in the next year (1874), barley being grown on both portions, the one from which 151·3 lbs. of nitrogen had been removed in clover yielded 69·4 lbs. in barley, whilst the one from which only 37·3 lbs. had been removed in the barley yielded only 39·1 lbs. in barley again.

In October, 1873, after the clover and barley had been removed, samples of soil were taken from 10 places on each portion; and determinations showed that there was a considerably higher percentage of nitrogen in the first 9 inches of the clover land than to the same depth of the barley land. This result, and the increased crop of barley succeeding the clover, are quite consistent with what is known of the influence of a clover crop as a preparation for a succeeding cereal one. But the actual amount of gain of nitrogen indicated in the surface soil was greater than the amount removed in the clover crops, which it seems difficult to suppose would be the case; though comparative samples were again taken 4 years later, and these also showed a higher percentage in the clover soil.

It is obvious that the clover, and the surface soil of the clover ground, had gained nitrogen either from the atmosphere or the subsoil; nor do the facts of the experiment afford evidence of the source of the nitrogen. There is, however, nothing in favour of the view that the atmosphere is the source, excepting that an explanation is needed; whilst it will be seen further on that there is direct evidence that the nitrogen of the soil is at any rate the source of much of the nitrogen of the Leguminosæ.

In view of the signal failure of clover on the nitrogen-exhausted arable soil, it is of much interest that large, but still declining crops, have been grown on a small plot of rich kitchen-garden ground for 31 years in succession.

The experiment was commenced in 1854. Samples of soil were taken in October, 1857, and in May, 1879, that is, with an interval of 21 seasons of growth. In 1857, only one sample was taken, and only to the depth of 9 inches; but in 1879 three were taken, in each case to the depth of twice 9, or 18 inches.

In 1857, the first 9 inches of soil showed more than 0·5 per cent. of nitrogen, or nearly 5 times as much as the exhausted arable soil in which clover would not grow. It is true the garden soil would also be 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 determinations of nitrogen made in the three 1879 samples of soil agreed very well, and they showed a reduction of 29 per cent. of the total nitrogen of the first 9 inches of soil since 1857. The reduction corresponded to a loss of 2732 lbs. per acre in the first 9 inches of depth during the 21 years; and it is to be remarked that with this great reduction in the stock of nitrogen in the soil there has also been a great falling off in the clover-growing capability of the soil, though mineral manures have from time to time been applied to a portion of the plot.

As nearly as can be estimated, the yield of nitrogen in the clover crops corresponded to about 200 lbs. per acre per annum over the 21 years; whilst the estimated loss of nitrogen by the first 9 inches of soil is about 130 lbs. per acre per annum; corresponding approximately to two-thirds of the amount removed in the crops. There is, however, reason to suppose that in the case of soils to which excessive amounts of farmyard manure are applied, there may be a loss by the evolution of free nitrogen, and so far as this may have occurred in this garden soil, there will be the less of the loss to be credited to the growing clover. On the other hand, in 1879, that is, at the end of the period under consideration, the second 9 inches of depth showed about three times as high a percentage as the subsoils of the arable fields, and even nearly twice as high a percentage as the surface soil of the field where the clover had so frequently failed. It cannot be doubted, therefore, that the subsoil of the garden plot had contributed to the yield of nitrogen in the clover.

There is, in fact, in the results of this experiment on a rich garden soil, if not absolute proof, certainly very strong ground for concluding, that much, and perhaps the whole, of the nitrogen of the 30 years of luxuriant clover crops was derived from the stores of nitrogen of the soil itself—supplemented only by the small amount of combined nitrogen annually coming down in the measurable aqueous deposits, and that condensed within the pores of the soil.

The Experimental Mixed Herbage Soils.—Over a period of 20 years, the mixed herbage of permanent grass land yielded an average of 33 lbs. of nitrogen per acre per annum without manure, and 55·6 lbs. with a mixed mineral manure, containing potash, but no nitrogen. Whence comes the increased amount of 22·6 lbs., under the influence of the purely mineral manure? In 1870, that is after 20 crops had been removed, samples of the soils were taken, and the nitrogen determined in them. Calculated per acre, the results indicated that the first 9 inches of depth of the mineral-manured plot contained, at the end of the 20 years, 506 lbs. less nitrogen than the unmanured plot to the same depth; corresponding to an annual reduction of 25·3 lbs. of nitrogen, against 22·6 lbs. per acre per annum more yielded in the crop. The coincidence is very remarkable; and the result can certainly leave little doubt that the increased amount of nitrogen in the crops had its source mainly, if not exclusively, in the surface soil.

In the case of the large crops of clover growing on the ordinary arable soil, it was assumed that, so far as the nitrogen was derived from the soil, it was mainly from the subsoil; but in the case of the clover on the rich garden soil it was concluded that it came largely from the upper layers; and here again, in the case of the mixed herbage, it is supposed that the increased yield is derived from the surface soil. In the first place, the surface soil of the garden ground was about four times, and that of the grass-land about twice as rich as that of the arable land. Further, it is known that clover growing on ordinary arable soil throws out much deep root. Then, again, although in the case of the mixed herbage experiment there was a considerable increase in the amount of leguminous herbage under the influence of the mineral (potash) manure, it was chiefly of the *Lathyrus pratensis*, which throws out a very large amount of root near the surface. There was also, in the later years, a considerable increase in the amount of gramineous herbage, more than would be expected under the direct influence of mineral manures, judging from their effects on the cereals on ordinary arable land. But, in the mixed herbage experiment the increase of the grasses did not take place at all prominently until after an increased growth of Leguminosæ; the surface soil of the grass land was about twice as rich in nitrogen as ordinary arable soil; and the grasses developed were characteristically surface-rooting species.

The Melilotus leucantha, and Trifolium repens, Soils.—On the arable soil on which red clover had, for many years, entirely failed to grow, and the percentage of nitrogen in the surface soil had been reduced to a very low point, the deep-rooted Melilotus grew very luxuriantly for several years. The seventh crop in succession has now been taken. The heaviest crop was obtained in the fifth year, 1882; its contents of nitrogen was between 140 and 150 lbs. per acre; and the average yield over the five years was about 92 lbs. In the sixth and seventh years the produce has been less; and less than on a second plot on which the same plant was grown for the first time in the sixth year. This result is indication that the growth is failing on the original plot. Still, the average yield of nitrogen per acre in this strong and deep-rooted plant, on soil where the much less powerful, yet still deep rooted red clover had entirely failed for many years, was over the 7 years between 70 and 80 lbs. per annum; whilst, side by side with it, both red and white clover, growing under exactly similar conditions of soil and season, yielded scarcely any produce at all.

After the removal of the very heavy crop of Melilotus in the fifth year, 1882, samples of soil were taken from the Melilotus and the white clover plots, to the depth of 6 times 9, or 54 inches.

For reasons already stated, the determinations of total nitrogen in subsoils are not applicable for calculations of the comparative condition of the two plots in that respect. But the following facts are of much significance. Determinations of moisture in the soils and subsoils, at each of the six depths, showed much less water remaining in the Melilotus than in the white clover soils; and the difference was by far the greater at the lower depths. Calculated per acre, it would appear that the Melilotus soil had lost to the depth of 54 inches, 540 tons more water than the white clover soil, and the action had doubtless extended lower still.

Thus the plant whose habit of growth, and especially whose range, and feeding capacity, of root, enabled it to take up much more water, and doubtless much more food, from the subsoil than the plant of weaker habit and more restricted root-development, assimilated a much larger amount of nitrogen over a given area, and a legitimate inference is that it had, in some way, derived more nitrogen, as well as water and other constituents, from the subsoil. Further evidence will be given on this point.

Nitrogen as Nitric Acid in Various Soils and Subsoils.

We now come to the consideration of evidence of another kind bearing upon the question of the soil-source of the nitrogen of our crops. It is in reference to this part of the subject that we have new and important results to communicate, but it will be desirable first to refer briefly to those which have already been published.

In the first place it should be stated that the water passing through three drain-gauges, containing respectively 20, 40, and 60 inches depth of unmanured and uncropped soil, and exposed to receive the rainfall, contained, taking the average of several consecutive years, nitrogen as nitric acid corresponding to about 40 lbs. of nitrogen per acre per annum. Of this, perhaps not much more than 5 lbs., and pretty certainly less than 10 lbs., would be due to combined nitrogen in rain, and condensed by the soil from the atmosphere. There would thus be from 30 to 35 lbs. annually due to the nitrification of the nitrogenous matter of these unmanured soils.

The following Table (p. 392), shows the amounts of nitrogen as nitric acid, found to specified depths, in soils under known, and for the most part strictly comparable, conditions.

In the first experiment, the land had been under rotation for many years, with no other manure than superphosphate applied every fourth year; that is for the root-crop commencing each course of—roots, barley, beans or fallow, and wheat. The samples of soil were taken from parallel plots, the difference between the two being that one had grown beans, and the other had been fallow. It will be seen that, down to the depth of 18 inches, the bean-soil contained 25·8 lbs. less nitrogen as nitric acid than the fallow soil.

In the second experiment, the land received both mineral and nitrogenous manure at the commencement of each rotation, and here, three years after the manuring, there was more nitrogen as nitric acid found, to the depth of 18 inches, than on the superphosphate plot; but 28·3 lbs. less after the growth of beans than after fallow.

In the third experiment, the manuring was the same as in the second, the samples were taken at the same period of the rotation, four years later, and to the depth of 27 inches, instead of only 18. Here there were 40·3 lbs. less nitrogen as nitric acid, to 27 inches of depth, after clover than after fallow.

In these three experiments, there is pretty clear evidence that the leguminous crops, beans and clover, had taken up nitrogen as nitric acid from the soil.

The fourth experiment has reference to land which had been alternately in wheat and fallow, without any manure, for nearly 30 years. The samples of soil taken after the removal of the wheat show very little nitrogen as nitric acid in the first 9 inches of depth, and only traces in the second 9 inches; and to the depth of 18 inches there were 31·1 lbs. less than in the land that had been left fallow. It is seen how completely the wheat had exhausted the upper layers of the soil of their nitric acid.

The fifth and sixth divisions of the Table show the amounts of nitrogen as nitric acid found in the autumn, to the depth of 27 inches, in soils under ordinary conditions as to manuring and cultivation, after having been left fallow since the harvest of the previous year. The quantities still remaining within that depth correspond to not much less than 60 lbs. per acre.

TABLE I.

Nitrogen as Nitric Acid, in various Soils at Rothamsted.

Previous cropping and manuring.	Nitrogen as nitric acid, per acre, lbs.			
	First 9 inches.	Second 9 inches.	Third 9 inches.	Total.
Rotation (Superphosphate); Agdell Field, Sept. 1878.				
Fallow	22·3	14·0	—	36·3
Beans	7·2	3·3	—	10·5
Difference....	15·1	10·7	—	25·8
Rotation (Full Manure); Agdell Field, Sept. 1878.				
Fallow	30·0	18·8	—	48·8
Beans	12·1	8·4	—	20·5
Difference....	17·9	10·4	—	28·3
Rotation (Full Manure); Agdell Field, Sept. 1882.				
Fallow	40·1	14·3	5·5	59·9
Clover	11·4	4·8	3·4	19·6
Difference....	28·7	9·5	2·1	40·3
Wheat and Fallow (Unmanured); Hoosfield, Sept. 1878.				
Fallow	28·5	5·2	—	33·7
Wheat	2·6	trace	—	2·6
Difference....	25·9	5·2	—	31·1
Ordinary Cultivation; Claycroft Field, Oct. 1881.				
Fallow................	16·4	26·5	15·9	58·8
Ordinary Cultivation; Foster's Field, Oct. 1881.				
Fallow................	14·6	24·6	17·3	56·5

Lastly, in the experiment in which various leguminous plants were grown on the land on which red clover had so persistently failed, samples of soil were taken to the depth of 6 times 9 inches after the removal of the very heavy crop of *Melilotus leucantha*, and of the very meagre crop of white clover, in 1882. At each depth, the Melilotus soil contained less nitrogen as nitric acid than the white clover soil. It will be remembered that the Melilotus subsoil had lost very much more water than the white clover soil; and, excluding the first 9 inches of depth, the reduction in the nitrogen as nitric acid was greater at the lower depths. In all, to the six depths, the Melilotus soil contained 17·8 lbs. less nitric nitrogen than the white clover soil.

There is here pretty direct evidence that the nitrogen as nitric acid within the soil has been the source of at any rate some of the increased nitrogen of the Melilotus ; though the quantity indicated is quite inadequate to account for the large amount of the increased yield. But the formation and the distribution of nitric acid within the soil are so dependent on the temporary conditions of temperature, moisture, and growth, that it is not to be expected that the amount found at any one time should account for the requirements of growth. Then, the action would doubtless extend deeper than is represented by the samples taken. It was suggested in the former paper that, with the strong and deeply distributing roots, the drawing up of water, and the greater disintegration and aëration accordingly, nitrification would probably be favoured in the lower layers, and that, if so, the supply would in a sense be cumulative. It was also suggested whether some of the nitrogen of the plant might not be taken up from the subsoil in other forms than that of nitric acid. These points will be further elucidated in the course of the discussion of the new results.

The New Results.

Nitrogen as Nitric Acid in Various Experimental Soils and Subsoils at Rothamsted.

We now come to the consideration of new determinations of nitrogen as nitric acid in various soils and subsoils. The determinations of nitric acid were made by Mr. D. A. Louis, by Schlösing's method, as nitric oxide, by the reaction with ferrous salts.

Towards the end of July, 1883, after the removal of the crops, samples of soil were taken, not this time from the *Melilotus* plot, but from two *Vicia sativa* plots, and from one *Trifolium repens* plot, in each case to the depth of 12 times 9 inches, or in all to the depth of 108 inches. Both the *Vicia sativa* plots gave fairly luxuriant crops, but there was no plant at all on the white clover plot. Samples of soil were also taken at the same time, and to the same depths from the immediately adjoining unmanured alternate wheat and fallow land, from the portion which had been fallow since the harvest of the previous year.

The following table (p. 395) shows the amounts of nitrogen as nitric acid, calculated per acre, at each depth in the wheat-fallow land, in the *Trifolium repens* plot, and in each of the *Vicia sativa* plots. It also shows the amounts, at each depth, more or less in the leguminous plot soils than in the wheat-fallow soil; and the amounts more or less in the *Vicia sativa* soils which yielded good crops, than in the *Trifolium repens* soil which gave no crop.

In the case of the wheat-fallow land, samples were taken at four places; and the figures given in the table are calculated from the results of determinations made in a mixture of the soils from the four holes, for each corresponding depth. In the case of each of the leguminous crop plots, samples were taken at two places; and, as in the case of the wheat-fallow plot, determinations of nitric acid were first made in a mixture of the samples from the two holes for each depth, but afterwards in the sample from each separate hole; and the results given for each depth are calculated from the mean of, first, the average of the determinations made in the samples from the individual holes, and, secondly, of the determinations made in the mixture from the two holes. Considerable differences were, in some cases, found in the amount of nitrogen as nitric acid in the separate samples from the same plot at corresponding depths; and these were found to be associated with great differences in the character of the subsoils, as to the proportions of clay, gravel, sand, &c., and with these, differences in the amounts of water, total nitrogen, &c. But whether the results for the individual holes, or for the two, be adopted, there is the same characteristic difference between plot and plot, as to their contents of nitrogen as nitric acid; that is to say, it is always very decidedly in the same direction, differing only more or less as to amount.

The first point of comparison that it is important to call attention to is the very marked difference between the amounts of nitrogen as nitric acid in the wheat-fallow land and in the *Trifolium repens* land.

At each depth, from the first to the twelfth, that is down to 108 inches in all, the *Trifolium repens* land contains much more nitrogen as nitric acid than the wheat-fallow land.

The two plots are absolutely adjoining in the same field. The one plot has been alternately wheat and fallow, without any manure, since 1850, or for more than 30 years. The other was sown with red clover 12 times during the 30 years 1848—1877; in 8 out of the last 10 trials, the plant died off in the winter or spring succeeding the

TABLE II.

Nitrogen as Nitric Acid, per acre, lbs., in the 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.	Series 1. Mineral manures.			+ or − wheat land.			+ or − Trifolium repens.	
		Trifolium repens. Plot 4.	Vicia sativa. Plot 4.	Vicia sativa. Plot 6.	Trifolium repens. Plot 4.	Vicia sativa. Plot 4.	Vicia sativa. Plot 6.	Vicia sativa. Plot 4.	Vicia sativa. Plot 6.
inches.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1—9	19·85	30·90	12·16	10·22	+11·05	−7·69	−9·63	−18·74	−20·68
10—18	8·05	27·73	4·11	2·72	+19·68	−3·94	−5·33	−23·62	−25·01
19—27	2·47*	8·44	1·37	1·08	+ 5·97	−1·10	−1·39	− 7·07	− 7·36
28—36	2·70	7·64	1·67	1·52	+ 4·94	−1·03	−1·18	− 5·97	− 6·12
37—45	1·62	9·07	4·58	2·51	+ 7·45	+2·96	+0·89	− 4·49	− 6·56
46—54	3·57	8·77	6·37	4·42	+ 5·20	+2·80	+0·85	− 2·40	− 4·35
55—63	3·84	7·92	7·16	4·52	+ 4·08	+3·32	+0·68	− 0·76	− 3·40
64—72	2·28	8·34	5·95	4·92	+ 6·06	+3·67	+2·64	− 2·39	− 3·42
73—81	1·48	8·27	4·54	4·81	+ 6·79	+3·06	+3·33	− 3·73	− 3·46
82—90	1·76	9·95	5·32	5·14	+ 8·19	+3·56	+3·38	− 4·63	− 4·81
91—99	2·94	9·16	5·66	6·40	+ 6·22	+2·72	+3·46	− 3·50	− 2·76
100—108	1·84	9·51	5·32	6·46	+ 7 67	+3·48	+4·62	− 4·19	− 3·05

Summary.

Depths.	Wheat-fallow land, unmanured.	Trifolium repens. Plot 4.	Vicia sativa. Plot 4.	Vicia sativa. Plot 6.	Trifolium repens. Plot 4.	Vicia sativa. Plot 4.	Vicia sativa. Plot 6.	Vicia sativa. Plot 4.	Vicia sativa. Plot 6.
1—27	30·37	67·07	17·64	14·02	+36·70	−12·73	−16·35	−49·43	−53·05
28—54	7·89	25·48	12·62	8·45	+17·59	+ 4·73	+ 0·56	−12·86	−17·03
55—81	7·60	24·53	17·65	14·25	+16·93	+10·05	+ 6·65	− 6·88	−10·28
82—108	6·54	28·62	16·30	18·00	+22·08	+ 9·76	+11·46	−12·32	−10·62
1—54	38·26	92·55	30·26	22·47	+54·29	− 8·00	−15·79	−62·29	−70·08
55—108	14·14	53·15	33·95	32·25	+39·01	+19·81	+18·11	−19·20	−20·90
1—18	27·90	58·63	16·27	12·94	+30·73	−11·63	−14·96	−42·36	−45·69
19—108	24·50	87·07	47·94	41·78	+62·57	+23·44	+17·28	−39·13	−45·29
1—108	52·40	145·70	64·21	54·72	+93·30	+11·81	+ 2·32	−81·49	−90·98

* According to the determinations on the mixture from the four holes, the result was 10·24 lbs., but this being obviously too high, determinations were made in the samples from each of the four holes separately, when the amount indicated in the third was found to be so abnormally high (= 25·9 lbs.) as to leave no doubt that there had been accidental contamination of the sample, and the results for the three other holes have accordingly been adopted.

sowing of the seed, in 4 of these without giving any crop, and in the other four only very small cuttings; and during the 30 years, consequent on the failure of the clover, 1 crop of wheat and 5 of barley have been taken, and the land was 12 years fallow. White clover (*Trifolium repens*) was then sown in 1878, 1880, 1881, and 1883. A small cutting was obtained in 1879, very small ones were taken in 1880 and 1881, and a small one in 1882, but none in 1883, so that the land was practically fallow when sampled. The plot had not received any nitrogenous manure for about 35 years. This and the other leguminous plant plots had, however, from time to time received mineral manures, containing phosphoric acid and potash, whilst the wheat land had not. It is known that potash manures favour the growth of *Leguminosæ*, and in the case of the soils of pasture land, the surface of which is much richer in nitrogen than that of ordinary arable soil, there is evidence that the increased amount of nitrogen taken up, both by the Gramineæ and the Leguminosæ, under the influence of the potash manure is derived from the rich surface soil itself, and probably as nitric acid. Of course, if phosphoric acid and potash in available condition were deficient, their application would of itself enhance the rate of nitrification even in an arable soil poor in nitrogen; but the extremely limited effect of such manures when applied to such soils for the growth of cereals, points to the conclusion that little if any of the excess of nitrogen as nitric acid in the *Trifolium repens* land, compared with that in the wheat-fallow land, is to be attributed to the action of the phosphoric acid and potash independently of the growth of the *Leguminosæ*.

Lastly, in March, 1881, and again in July, 1883, the surface soil of both plots was found to be very low in nitrogen determinable by soda-lime; that of the clover-land containing not much more, and that of the wheat-fallow land rather less, than 0·1 per cent. According to the figures, the leguminous crop soils contained from 400 to 500 lbs. more combined nitrogen per acre in the first 9 inches of depth than the wheat-fallow soil. To the total depth of 108 inches, the plots show an average of not much less than 20,000 lbs. of combined nitrogen per acre; excepting that the *Vicia sativa* plot 6 shows considerably less than the others, owing to the sandy and gravelly character of the samples of its subsoil at the lower depths, whilst the *Trifolium repens* soil, the samples of which were more clayey, shows the highest of the series.

Thus, independently of the application of mineral manures to the leguminous plant plots, the characteristic difference in the history of the two plots now under consideration is—that the one had grown a gramineous crop alternately with fallow for more than 30 years, and the other had, during the same period, grown six gramineous crops, and frequently been fallow, but it had been sown 12 times with red clover, and during the immediately preceding six years 4 times with white clover. That is to say, the chief distinction is, that the one had, from time to time, especially in the earlier and later years, grown a leguminous crop, whilst the other had not; and the leguminous crop soil is found to contain, down to the depth of 108 inches, nearly three times as much nitrogen as nitric acid as the gramineous crop soil.

The difference is much the greater in the first 18 inches of depth, indicating more active nitrification in the superficial layers; and this is doubtless mainly if not wholly due to the accumulation of more nitrogenous crop-residue from the leguminous than from the gramineous growth. It may here be mentioned that the amount of nitrogen removed in the *Trifolium repens* crops averaged over the preceding four years about 30 lbs. per acre per annum, but the immediately preceding crop (that of 1882) would probably remove between 60 and 70 lbs. How much beyond this would be contained in the crop-residue, and how much it would be in excess of that in the residue from the wheat crop, we have not the means of estimating; but it may safely be concluded that it would be considerably less than sufficient to supply the excess of about 90 lbs. of nitric nitrogen found to the depth examined in the soil of the *Trifolium repens* plot more than in the soil of the wheat-fallow plot; whilst, as has been shown, there was probably a material amount of drainage below that depth, which, according to the figures, would be much richer in nitric acid than any drainage from the wheat-fallow soil.

Part of the increased amount of nitric nitrogen in the lower layers of the leguminous plant soil may, however, also be due to washing down from the surface. On this point, it should be stated that, from September, 1882, to the end of February, 1883, the rain-gauge showed about 24 inches of rain, and the drain-gauges about 18 inches of drainage, so that the autumn and winter conditions had been conducive to both distribution and loss of nitric acid. In March and April there was very little of either rain or drainage; in May there was less than the average amount of rain, but more than the average amount of drainage; in June both rain and drainage were below average. Lastly, in July there was considerably more than average of both rain and drainage, nearly half of each occurring before the commencement of the soil-sampling on the 17th, and most of the remainder before its completion on the 26th.

Thus, not only had the conditions of the previous autumn and winter been favourable for distribution and loss, but the period immediately preceding and during the soil-sampling, which was also that of active nitrification, were such as to favour distribution, if not even some loss by drainage.

It is, however, not easy to suppose that the whole of the excess of nitric nitrogen in the lower layers of the *Trifolium repens* soil is due to washing down from the surface.

That the increased amount of nitric acid found in the lower layers, not only of the *Trifolium repens*, but also of the *Vicia sativa* soils, is not wholly due to more active nitrification in the surface, and percolation downwards, would appear from the fact that the surface soil of each of the three leguminous plant plots, after more than 30 years of greater removal of nitrogen in produce, due chiefly to the frequent growth of leguminous crops, still remains somewhat richer in nitrogen than that of the wheat-fallow plot. Or, if this is to be attributed to the accumulation of nitrogenous crop residue near the surface, in amount more than compensating for the exhaustion of nitrogen by growth, this means, unless indeed we assume that it has come from the atmosphere, that the nitrogen has been derived from the stores of the subsoil, and if as nitric acid, obviously not wholly from the surface soil.

An obvious difficulty in the way of the assumption that the increased assimilation of nitrogen by the *Leguminosæ* is due to a supply of nitric acid by the nitrification of the nitrogen of the subsoil, 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 nitrate of soda or nitrate of lime, 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 subsoil, it is probable that it will be associated with other constituents, liberated, and so rendered available, at the same time.

Upon the whole, the indication certainly is, that nitrification is more active under the influence of leguminous than of gramineous growth and crop-residue.

In Mr. Warington's paper "On Nitrification" (Trans., 1884, 637), he states that samples of subsoil taken at a considerable depth, with precautions to exclude any roots or other organic matter, when introduced into a sterilised nitrogenous liquid, did not induce nitrification; the conclusion being that the subsoil was destitute of nitrifying organisms. This is obviously no proof that the nitrogenous matter of the subsoil would not nitrify if the organisms, with the other necessary conditions, were present. Indeed, results will be adduced further on, pointing to the conclusion that nitrification does take place in subsoils under such conditions.

An obvious conclusion from the results given in the table is that, in the case of a soil under leguminous growth, the conditions are favourable for the development of the nitrifying organism; but, in what way, the evidence at present at command does not enable us to explain. If, however, this view should be confirmed, an important step would be gained towards the more complete explanation of the source of the nitrogen of the *Leguminosæ*.

In the case of the experiments now under consideration, the large amount of nitrogen as nitric acid was found in the soil where previously the deep-rooting red clover had frequently been sown and failed, but recently the shallow rooting *Trifolium repens* had been grown. The increased amount of nitrogen as nitric acid, not only in the upper but in the lower layers, must therefore have had its source, either wholly in the more active nitrification in the upper layers, and subsequent percolation downwards, against which view reasons have been given above, or it is only in part due to this source, and in a greater or less degree to the passage downwards of the nitrifying organism, and the nitrification of the nitrogen of the subsoil.

On the view here supposed, there would be much less difficulty in accounting for a large amount of the nitrogen of the subsoil thus becoming available to such deep and strong rooted plants as the *Melilotus leucantha*. With the penetration of the roots, channels are formed, by which, in addition to those made by worms, the nitrifying organism may pass downwards in association with recent and decomposable organic matter. There is direct evidence that much water is drawn up, and air, and some water, with its contents, must necessarily go down. We have thus all the conditions necessary for the supply of nitrogen as nitric acid to the roots, provided only the nitrogen of the subsoil is subject to nitrification.

On the assumption, therefore, that leguminous growth and crop-residue are favourable for the development of the nitrifying organism, it would follow that, if the conditions of soil are such as to allow of the establishment of a good plant, and to meet its requirements for mineral food, the greater its root development, the greater will be the amount of nitric acid formed, and of nitrogen so rendered available to the plant from the subsoil.

It is quite in accordance with such an explanation that it is only the deep and strong rooted *Leguminosæ* that yield very large amounts of nitrogen over a given area in their crops. It is further consistent with the supposition that the source of the nitrogen is the soil and not the atmosphere, that when such crops have been grown for some years, and have removed very large amounts of nitrogen, they cannot be grown again on the same land for many years afterwards; the explanation apparently being that, within the range of the roots of the particular plant, the stock of organic nitrogen in a condition susceptible to nitrification, and perhaps also the supply of the necessary mineral constituents, in an available condition, had been for the time exhausted. It is also consistent with the idea of a soil-source, that when the same description of leguminous plant has been grown year after year until it fails, another description, with different root-habit and root-range, may grow luxuriantly for some years, and then in its turn decline or fail.

There is of course the alternative that the soil and subsoil may be the source of the nitrogen, and yet that the plant may take it up in other forms than as nitric acid, as ammonia, or as organic nitrogen.

We have shown that, in the growth of fungi, as in the case of "*Fairy rings*," both the organic nitrogen and the organic carbon of the soil are much reduced, and there is nothing in the conditions of growth of such plants, so far as they are known, at all inconsistent with the supposition that they take up their nitrogen and carbon directly from organic matter. The evolution of carbonic acid is a characteristic of the accumulative process of such plants; and it is found that the proportion of carbon to nitrogen finally fixed in the plant, is lower than the proportion of carbon to nitrogen lost by the soil.

The characteristic conditions of accumulation and growth of green leaved plants are, however, essentially different; and such as to require that clear experimental evidence should be adduced before the conclusion can be accepted that they take up any material amount of their nitrogen and carbon from the same sources, and in the same manner, as the plants devoid of chlorophyll. Supposing the *Leguminosæ*, for example, were able to take up nitrogen directly as organic nitrogen from the subsoil; it must either be assumed that they take up carbon also, as do the fungi, or that they break up the organic compound, and in some way or other eliminate the carbon—which also must be eliminated in the case of nitrification.

Now, in the ordinary clay subsoil at Rothamsted, the relation of the carbon to the nitrogen is as 6 or 8 to 1, but in our common leguminous crops it is about 15 to 1. Hence, even if the whole of the carbon in association with nitrogen in the subsoil were taken up by the plant, it would not be sufficient to supply the whole of the carbon, and there would still be room for much assimilation from carbonic acid under chlorophyll action.

Or, it may be assumed that only the carbon of the *nitrogenous compounds* of the plant may be taken up with the nitrogen by the roots, from the subsoil. This would require less than $3\frac{1}{2}$ parts of carbon to 1 of nitrogen to be so supplied. So far, however, as direct experimental evidence is available on the point, it is, to say the least, doubtful, whether carbon supplied to the roots even as carbonic acid is assimilated by green leaved plants; nor are we aware of any experimental evidence showing that such plants assimilate carbon presented to their roots in other forms of combination.

Thus, whilst, so far as existing knowledge goes, physiological considerations seem to militate against the supposition that green leaved plants take up carbon from organic matter in the subsoil, the only ground for assuming that they so take up their nitrogen is that as yet other explanations are quantitatively inadequate to account for the facts of growth.*

In defect of clearer evidence than we at present possess, leading to a conclusion which would approximate rather than differentiate the processes of accumulation of fungi and of green leaved plants, it will be of interest to follow up more closely, clues that seem to promise at least a more consistent solution of our difficulty as to the source of the nitrogen of the *Leguminosæ*.

This brings us to a consideration of the results given in the other columns of the Table II (p. 395).

It has been seen that the *Trifolium repens* soil showed more nitric nitrogen at every depth down to 12 times 9 inches, or in all to 108 inches, than the wheat-fallow soil. But the other columns show that in the case of both plots, where another leguminous plant, the *Vicia sativa*, had yielded fair crops, the amount of nitrogen as nitric acid was very much less. The inference is that the *Vicia* had taken up nitric acid and assimilated its nitrogen.

To go a little more into detail: each of the *Vicia* plots shows less nitric acid, at every depth down to 108 inches, than the *Trifolium repens* plot; but the difference is by far the greatest in the upper layers, and especially in the first 18 inches from the surface; and this is the range within which this plant throws out by far the larger amount of root. But the reduction is very distinct below this point; and the supposition is that water had been brought up from below, and with it nitric acid. In fact, the determinations showed less water in the soils of both the *Vicia* plots, at every depth, excepting the eleventh, than in the corresponding soils of the *Trifolium repens* plot, the eleventh depth of which showed the lowest proportion of soil of any in the whole series of plots and depths, and a very large amount of stones. Reckoning to the total depth of 108 inches, the mean for the two *Vicia* plots shows less water, corresponding to between 6 and 7 inches of rain, or to betweeen 600 and 700 tons of water per acre. Making full allowance for all irregularities at individual depths, or between hole and hole, due to variations in the character of the subsoils, there is here direct proof of much water, doubtless with its soluble contents, having been drawn up from the subsoil.

* The cases of the so-called "Insectivorous Plants" are obviously not parallel.

Calculated per acre, there is, in the one case 81·49 lbs., and in the other 90·98, lbs. less nitrogen as nitric acid in the *Vicia* soils than in the *Trifolium* soil, down to the total depth of 108 inches; nearly half of the deficiency being below the first 18 inches. Even supposing that no more nitrification had taken place in the *Vicia* soils where there was growth, than in the *Trifolium* soil where there was no growth, the difference which the actual results indicate would account for a large proportion of the nitrogen of the crops.

It has been shown, however, that the conditions of the weather had been such as to lead to the conclusion that there was probably some loss of nitric acid by drainage, which would obviously affect the *Trifolium repens* plot, where there was no growth, considerably more than the *Vicia* plots where there was growth, and a constant tendency to the drawing up of water with its contents. It is obvious that, so far as this has been the case, the amount of nitrogen as nitric acid found in the *Trifolium repens* plot down to the depth examined, does not represent the whole that had been formed within those limits. Now the amount of nitrogen as nitric acid remaining in the soil of one *Vicia* plot is estimated at 64·2 lbs. per acre, and the amount of nitrogen in the crop at 126 lbs., in all 190·2 lbs., or about 44·5 lbs. more than was found as nitric acid in the *Trifolium repens* soil; whilst in the case of the other *Vicia* plot, the amount of nitric nitrogen in the soil was estimated at 54·7 lbs., and the amount of nitrogen in the crop at 143·7 lbs., in all, in soil and crop, 198·4 lbs., or 52·7 lbs. more than was found in the *Trifolium repens* plot. On the supposition, therefore, that the whole of the nitrogen of the *Vicia* crops had been taken up as nitric acid, we have to assume that in the one *Vicia* plot 44·5 lbs., and in the other 52·7 lbs., more nitrogen as nitric acid was available than in the *Trifolium repens* plot to the depth examined; and this might be accounted for, partly by less loss by drainage from the *Vicia* plots, and partly by more nitrification under the influence of the growing crops, or their residues.

But, even if it be admitted that the source of the nitrogen of the *Vicia* crops is thus satisfactorily explained for the year in question, it is to be borne in mind that the same plots had grown the same plant in each of the five preceding years, with, on the two plots, an estimated average yield of nitrogen of rather over 40 lbs. in 1878, nearly 47 lbs. in 1879 and in 1880, nearly 70 lbs. in 1881, and between 140 and 150 lbs. in 1882; or an average of about 70 lbs. per acre per annum over the five immediately preceding years. But the amount of nitrogen taken up each year must have been much more than this, as each of the crops must have left nitrogenous crop-residue near the surface, which would yield nitric acid for the succeeding crop or crops. Much of the nitrogen of the removed crops and the residue combined, must obviously be due to other sources than the original surface soil; and if to the subsoil, it must either have been taken up as organic nitrogen (or ammonia), or, as it would seem in 1883, as nitric acid; and in that case the annual nitrification beyond that of the previous crop-residue near the surface, must have yielded approximately as much nitrogen as was contained in the removed crops. As the *Vicia* crops were large in 1882, so also would their residue be proportionally large, and contribute a correspondingly large amount of nitric acid near the surface for the crop of 1883. But the crop of 1883 was nearly as large, and it, in its turn, would leave a correspondingly large residue, leaving approximately the whole of the nitrogen removed in the crop to be otherwise provided than from previous residue.

In conclusion, in reference to this series of experiments, it must be admitted that, without relying at all rigidly on the exact numerical results obtained under circumstances of so much difficulty as is involved in such an inquiry, these results, taken in conjunction with all that have been before adduced, justify the conclusion that much, if not the whole, of the nitrogen of the *Vicia sativa* crops had been obtained from nitric acid within the soil.

The next Table (III, p. 404), relates to the soil where beans had been grown almost continuously for about 30 years, the land had then been fallow for between 4 and 5 years, to 1882 inclusive, and the stock of nitrogen in the surface soil had been much reduced, and was in fact very low. Barley and clover were sown in 1883. The clover came up extremely well, and was very luxuriant even that year, much interfering with the growth of the barley; and this year, 1884, it has given two heavy crops.

It is certainly contrary to what would be anticipated, that, on this bean-exhausted soil, with its low percentage of nitrogen in the upper layers, very luxuriant crops of clover should be grown. Nor have we any data as to the changes in the soil and subsoil under the influence of this luxuriant growth. It is to be borne in mind, however, that the land had been fallow for several years, that clover had not been grown on it for perhaps 40 years or more, and that it succeeded a crop, though a leguminous one, of very widely different root-habit and root-range. Whether, as the result of the fallowing or not, it is obvious that poor as the surface soil was in total nitrogen, it was in favourable condition, both as to nitrogen and mineral supply, for the establishment of a good plant. This accomplished, it may safely be concluded, that the plant would develop much root in the subsoil, that it would, directly or indirectly, draw up much water from below the surface, and that, with this, it would take up nitrogen as nitric acid, as well as other constituents, from the subsoil.

TABLE III.

Nitrogen as Nitric Acid per acre, lbs., in Soils of Experimental Plots; Beans many years in succession; Fallow last 4½ years.

Geescroft Field, Rothamsted. Sampled April 9—13*th*, 1883.

Depths.	Without manure.	Mineral manure		Farmyard manure.
		Alone.	And ammonium salts or nitrate.	
	Plots 1 and 2.	Plot 8.	Plots 9 and 10.	Plot 42.
inches.	lbs.	lbs.	lbs.	lbs.
1—9	4·28	3·34	3·46	13·57
10—18	5·52	6·69	5·81	8·76
19—27	4·81	4·33	4·12	7·70
28—36	2·69	2·33	4·14	8·51
37—45	2·68	1·25	2·28	4·36
46—54	1·90	1·05	2·34	1·85
55—63	2·60	0·81	1·48	1·71
64—72	3·47	0·92	1·75	4·00
Summary.				
1—27	14·61	14·36	13·39	30·03
28—54	7·27	4·63	8·76	14·72
55—72	6·07	1·73	3·23	5·71
1—36	17·30	16·69	17·53	38·54
37—72	10·65	4·03	7·85	11·92
1—72	27·95	20·72	25·38	50·46

Not only was the total nitrogen in the surface soil very low (about 0·1 per cent. in the dry sifted soil), but the table affords direct experimental evidence that the amount of nitric acid already existing in the soil when the barley and clover were sown was extremely small. Even in the case of the farmyard manure plot, and much more so in that of the other plots, it was entirely inadequate to meet the requirements of the luxuriant crops of clover.

The soils were sampled from April 9—13, 1883. It has been already stated that the land had been fallow for several years, so that there would be a minimum amount of crop-residue near the surface; and since, during the autumn and winter of 1882—3, there had been a great excess of both rain and drainage, it could not be expected that there would be much of the probably limited amount of nitric acid formed in the previous summer and autumn remaining in the soil in April. Indeed, excepting in the case of the farmyard manure plot, there is more nitrogen as nitric acid in the second and third, and in one case in the fourth depth, than in the first, thus affording direct evidence of washing down. In fact, in the first three depths, that is, down to 27 inches, there is only about half as much nitrogen as nitric acid as, to the same depth, in the wheat-fallow soil sampled in the following July, and there is also less in the next five depths.

Here, then, we have a surface soil with the total nitrogen very much reduced by previous treatment, and very low, in both surface and subsoil, very small amounts of ready-formed nitric acid, and probably a minimum amount of crop-residue near the surface for decomposition and nitrification, when the red clover was sown. Yet very luxuriant crops were grown, carrying off more than 200 lbs. of nitrogen per acre, and, of course, leaving a highly nitrogenous crop-residue besides.

Whence comes this nitrogen? The alternatives are, 1—that it has been supplied from the atmosphere, in favour of which view there is nothing excepting that it would afford an explanation otherwise not very obvious; 2—that it has been derived directly from the organic nitrogen of the soil and subsoil, for which again there is as yet no proof, whilst there are physiological reasons against it; 3—that under the influence of the once well started leguminous growth, with its excretions and residue, the development of the nitrifying organism is favoured, first in the upper and richer, and afterwards in the lower and poorer layers, and that thus the organic nitrogen of the soil and subsoil has been gradually rendered available for the exigencies of growth; and that the supply was largely derived from the subsoil may be inferred from the fact that, after the growth of clover, the surface soil is generally found to be richer in total nitrogen determinable by the soda-lime method. For this explanation, too, it is freely admitted that proof is wanting; but there is, at any rate, more evidence from analogy in its favour than for either of the other solutions suggested.

The next results relate to plots on which rotation experiments have been conducted through 9 courses of 4 years each, that is, over a period of 36 years in all. The course of cropping has been, 1—roots; 2—barley; 3—clover, or beans, or fallow; 4—wheat. The manures indicated at the head of the columns in the table (p. 406), were only applied for the roots commencing each course, that is, once in 4 years; and the samples of soil were taken after the wheat crop concluding the ninth course, and consequently four years after the last application of manure.

TABLE IV.

Nitrogen as Nitric Acid per acre, lbs., in Soils of Experimental Plots, after Rotation 36 years. Roots; Barley; Clover, or Beans, or Fallow; Wheat.

Agdell Field, Rothamsted. Sampled November 15, 1883, *to January* 4, 1884.

Depths.	Mineral and nitrogenous manure. Roots fed on the land.		Superphosphate only. Roots carted.	
	Fallow. Plots 1 and 2.	Clover or beans. Plots 3 and 4.	Fallow. Plots 13 and 14.	Clover or beans. Plots 15 and 16.
inches.	lbs.	lbs.	lbs.	lbs.
1—9	3·44	6·13	3·36	3·66
10—18	3·11	4·41	2·64	3·48
19—27	0·79	1·63	0·95	1·51
28—36	1·01	1·30	0·90	0·96
37—45	0·81	1·52	0·45	1·18
46—54	0·61	0·81	0·53	1·55
55—63	0·77	2·23	1·22	0·85
64—72	0·89	1·68	1·49	1·57
73—81	5	2·44	2·97	1·67
82—90	2·03	2·08	2·78	2·00
91—99	1·53	2·13	4·81	2·36
100—108	3·75	2·83	3·11	0·90

Summary.

1—27	7·34	12·17	6·95	8·65
28—54	2·43	3·63	1·88	3·69
55—81	2·31	6·35	5·68	4·09
82—108	7·31	7·04	10·70	5·26
1—54	9·77	15·80	8·83	12·34
55—108	9·62	13·39	16·38	9·35
1—18	6·55	10·54	6·00	7·14
19—108	12·84	18·65	19·21	14·55
1—108	19·39	29·19	25·21	21·69

The first two columns of the table show the amounts of nitrogen as nitric acid down to the depth of 12 times 9 inches, or in all to 108 inches, in the soils where a full manure, both mineral and nitrogenous, had been applied every fourth year; and the third and fourth columns show the amounts in those where superphosphate of lime only had been applied, once in four years; the determinations being made, in each case, four years after the application.

Each of these plots is again divided into two:—One-half being left fallow, and the other growing clover or beans, in the third year of the course. That is to say, from one-half—that in fallow—there is no crop, and therefore no nitrogen removed in the third year of the course, whilst from the other a highly nitrogenous leguminous crop, clover or beans, is removed.

A further distinction between the differently manured plots is, that on the highly manured plot the roots were fed on the land, whilst they were entirely removed from the superphosphate plot. Thus, the one plot is not only very much more highly manured, but it is otherwise subjected to much less exhausting treatment.

The soil sampling was conducted between November 15, 1883, and January 4, 1884, the operations being very much interfered with by rain. It has already been stated, that there was a great deal of rain, and a great deal of drainage, during the previous autumn and winter, 1882—3. There was, however, very little drainage in either March or April, a fair amount in May, very little in June, a good deal in July, scarcely any in August; but there were considerable quantities in September, October, November, and December.

Upon the whole, therefore, the conditions during the previous twelve months or more were such as to induce distribution, and loss, of nitric acid by drainage.

The first point to remark is that, under these circumstances, the amounts of nitrogen as nitric acid found are in all cases very small; the highest amount being little more than half as much as was found in the wheat-fallow soil in Hoosfield, sampled before the loss by drainage of August, September, October, and November. Next, there is a general tendency to an increase in the amount in the lower layers, indicating washing down, and probably loss below.

Comparing plot with plot, and taking first the highly manured and less exhausted plot, it is seen that the figures in the two columns are very consistent. The amount of nitrogen as nitric acid is higher at every depth (excepting the twelfth) where clover had been grown, than where the land had been fallow, in 1882. That is to say, where the land had been fallow there was no growing plant to take up the nitric acid formed; there would be a minimum of crop-residue, and the smaller amount of nitric acid would be subject to drainage, both throughout the fallow period, and during the succeeding very wet autumn and winter. On the other portion, the growing clover would take up nitric acid, and leave a highly nitrogenous crop-residue near the surface. There would thus be more nitric acid formed, and remaining, within the range of the soil-sampling; and as a matter of fact the wheat crop of 1883, succeeding the clover, was larger, and took up more nitrogen, than that after the fallow. Indeed, over the 36 years of the experiment, whilst the clover or bean plot has yielded an average of 68·4 lbs.

of nitrogen per acre per annum in the crops, the fallow plot has only yielded 47 lbs.; or deducting the amounts of nitrogen applied in manures, the yield in the crops of the clover or bean plot has been 34 lbs., and that of the fallow plot only 12·6 lbs. per acre per annum.

This experiment affords an illustration of the loss of nitrogen that the land may sustain by fallow in a wet season, and of the benefits arising from the ground being covered with a crop which takes up the nitric acid as it is produced; and obviously the effect will be the greater when that crop is a leguminous one if, as has been suggested, its growth and residue are favourable to the development of the nitrifying organisms, and the formation of nitric acid, the nitrogen of which is conserved by the plant.

We turn now to the results relating to the much more exhausted plot, receiving only superphosphate of lime every 4 years, and no nitrogen in manure, and from which the root-crops are entirely removed instead of being fed on the land. From the fallow portion of this plot, an average of 31·1 lbs., but from the clover or bean portion of 44·4 lbs. of nitrogen has been removed per acre per annum in the crops. In 1882, about 150 lbs. of nitrogen were removed in the crop on the clover portion, the fallow portion losing none except by drainage; and after this the wheat crop of 1883 removed rather more nitrogen from the fallow portion.

The influence of the clover crop residue is nevertheless still seen in the somewhat higher amount of nitrogen as nitric acid in the first six depths; whereas, with the tendency to passage downwards, rather than to drawing upwards, during the fallow period, there is more nitric acid in the lower layers of the fallow portion.

To conclude in relation to the results of these rotation plots:—they do not contribute very direct, or very important evidence, on the main point of our inquiry—that of the soil-source of the nitrogen of our crops generally, and of the *Leguminosæ* in particular; but so far as they go they are found, on detailed examination, to be consistent in their indications with those which have gone before, and which are more definite in character.

The Sources of the Fertility of some Manitoba Prairie Soils.

If then, the mineral constituents not being deficient, and being in available condition, the fertility of a soil is largely to be measured by the amount of nitrogen it contains, and the degree in which it is subject to nitrification, it becomes a matter of interest to determine the characters of virgin prairie soils in these respects.

In our former paper, given two years ago, we gave the determinations of nitrogen in some prairie soils.

In a sample of Illinois prairie soil, supplied some years ago by Sir James Caird to Dr. Voelcker for analysis, the amount of nitrogen found in it by him, and also at Rothamsted, corresponded to 0·25 per cent. in the dry mixed soil and subsoil; while in the separate surface soil Dr. Voelcker found 0·33 per cent.

Again, in 1882 between forty and fifty samples of soil from the North-west Territory, taken at intervals between Winnipeg and the Rocky Mountains, were sent over to the High Commissioner in London for exhibition. They were exhibited in glass tubes 4 feet in length, and were stated to represent the core of soil and subsoil to that depth. Samples of the surface soils of three of these were kindly supplied to us for the determination of nitrogen in them. The following results were obtained :—

	Per cent. nitrogen in dry soil.
No. 1. From Portage la Prairie, about 60 miles from Winnipeg, under cultivation several years	0·2471
No. 2. From the Saskatchewan district, 140 miles from Winnipeg, under cultivation less time than No. 1	0·3027
No. 3. About 40 miles from Fort Ellice, a virgin soil	0·2500

Now these soils are probably about twice as rich in nitrogen as the average of arable soils in Great Britain, and perhaps about as rich as the average of the surface soils of permanent pasture land; and as their nitrogen has its source in the accumulation from ages of natural vegetation, with little or no removal, except by drainage, and they do in fact yield large crops, it is to be supposed that they are not deficient in the necessary mineral supplies. Indeed, in Dr. Voelcker's report on four Illinois prairie soils, he calls attention to their richness in potash and other mineral constituents; the amount of lime, however, being somewhat low.

In the case of these soils, we did no more than determine the nitrogen by soda-lime. But it is obvious that if the views we have maintained in the preceding part of this paper are correct, it would be a matter of much interest to determine the degree of susceptibility to nitrification of such soils. In a short visit paid by one of us to Manitoba in the autumn of 1882, a few samples of soil were collected for examination, and it was also arranged at Winnipeg that special samples should be collected. But notwithstanding the infallible baggage-cheque system of the American continent, the bag containing the samples was lost, and the special samples from Winnipeg have not yet reached us, but are still promised.

However, the Deputy Minister of Agriculture at Winnipeg, Mr. Acton Burrows, sent a series of samples last year (1883), to be exhibited at the offices of the Canadian Pacific Railway Company in London; and by his directions, and with the kind co-operation of Mr. Begg, the Land Agent of the Company in London, we have been enabled to obtain fair and sufficient samples of those sent over as above referred to. As the Tables V, VI, VII, and VIII, which follow, recording the results, show, one series of samples come from Niverville, one from Brandon, one from Selkirk, and one from Winnipeg. In each case, four samples were taken, representing respectively the first, second, third, and fourth foot of depth.

In all the samples, we have in the first place determined the total nitrogen, and the total carbon.

Samples were then extracted with water, by the aid of the water-pump, and the nitrogen as nitric acid determined in the extracts. The amount of nitric acid so found in the sample as received being very largely dependent on the conditions of moisture and preservation of the sample, the results of the first determinations are of little significance. After the first extraction, each sample, in a suitable condition as to moisture, was exposed in a shallow dish, covered with a glass plate, and all were subject to the same conditions as to temperature, which, however, were not uniform in the different periods. Then, after a given time, at first 28 days, but afterwards generally for a longer and not always a uniform period, the sample was again extracted, and the nitrogen as nitric acid again determined; and as the Tables show, the process was repeated 8 times, the work extending from March, 1883, to April, 1884.

It is obvious that, by repeated extraction, the soluble mineral matters of the soils would be washed out; and it became a question whether the reduced nitrification in some cases might not be due to a deficiency of mineral matter for the development of the nitrifying organisms, or of the formation of nitrates. Hence, after the fourth extraction, potassium phosphate, magnesium sulphate, and calcium carbonate, were added to the samples. It was evident from the character of the extracts that too much of these had been added, and in the fifth extract scarcely any nitric acid was obtained. After this extraction, however, the action recommenced with some energy, and in the Tables the results obtained in the fifth and sixth extractions are given together.

Again, after the seventh extraction, it was decided to see whether the action would be increased if the exhausted soils were seeded with nitrifying organisms. Accordingly, 0·1 gram of rich garden soil was well mixed with each of the subsoils in which the action had much diminished, and the results obtained after this treatment are given within brackets, thus [ ], in the last column of each of the Tables.

We now turn to the consideration of the results obtained. The percentages of nitrogen (determined by the soda-lime method) are given in the first column of Table V; and the percentages of carbon, and its proportion to the nitrogen, in the surface soils, are given in Table IX, p. 419. The amount of carbon found, and its proportion to the nitrogen, in some of the subsoils, are, however, so high, that it is obvious the samples were not quite free from particles of undecomposed vegetable residue, although all that was visible was picked out before the samples were submitted to analysis. The subsoil carbon results are therefore not recorded.

The first soil, that from Niverville, about 44 miles west of Winnipeg, had been broken up from prairie five or six years, and had grown 5 crops of cereals.

The percentage of nitrogen in the dry soil of the first 12 inches of depth is 0·261, or nearly twice as high as in the first 6 or 9 inches of ordinary arable land, and about as high as in the surface soil of pasture land, in Great Britain. Even the second 12 inches of depth is richer than our surface arable soils. The third 12 inches is about as rich as the second 9 inches of the Rothamsted soils, but the fourth is low. Here, however, we have a depth of 24 inches very much richer than the first 9 inches of our own arable soils.

The soil from Brandon, about 132 miles west of Winnipeg, was first broken up in 1882, back set in 1883, and grew 25 bushels of wheat per acre that year.

This soil is not so rich in nitrogen as that from Niverville. Still the dry soil of the first 12 inches of depth contains 0·187 per cent. of nitrogen, and is as rich as the first 6 or 9 inches of good old arable soil, and the second 12 inches is about equal to the exhausted surface soil at Rothamsted; the third 12 inches is about equal to the second 9 inches of the Rothamsted soils; but the fourth depth is very poor.

The soil from Selkirk was taken from a farm which had been in cultivation for 25 years, but from a portion near the buildings which had never been broken up.

Here it is seen that there is an extremely high percentage of nitrogen in the first 12 inches of depth (0·618), and in the second 12 inches as high a percentage as in ordinary pasture surface soil (0·264). The third and fourth depths are about as rich as the Rothamsted subsoils. It might be supposed that the first 12 inches had been contaminated by manure from the buildings, were it not that the second 12 inches also shows a high result.

Lastly, the soil from Winnipeg had been broken up from prairie about 5 years, had been ploughed and trenched, had been manured

TABLE V.

Percentage of Nitrogen in some Manitoba Prairie Soils and Subsoils, also Results showing the Amounts of Nitrogen Nitrified, on exposure for given Periods, &c.

Depths.	Per cent. nitrogen in dry soil.	Nitrogen as nitric acid per million dry soil.														
		Original.	Periods of exposure.													
			1st.		2nd.		3rd.		4th.		5th and 6th.*		7th.		8th.†	
			Soil from Niverville.													
inches.	per cent.		days.		days.		days.		days.		days.		days.		days.	
1—12	0·261	2·70	28	14·33	28	9·44	87	45·75	35	lost	79	(0·14)	28	4·65	49	9·32
13—24	0·169	0·18	28	3·13	28	3·23	85	1·89	38	4·14	79	(3·14)	28	0·57	28	[6·66]
25—36	0·069	0·62	26	0·38	28	0·35	82	0·34	38	0·11	79	(0·78)	28	0·24	28	[1·28]
37—48	0·038	0·74	28	0·44	28	0·59	74	0·51	38	0·29	79	(1·10)	28	0·18	28	[0·63]
			Soil from Brandon.													
1—12	0·187	0·23	28	9·13	28	8·82	87	33·55	35	12·51	79	(10·15)	28	6·94	49	8·34
13—24	0·109	1·50	28	‡1·43	28	1·05	85	3·27	35	5·70	79	(4·03)	28	2·37	49	lost
25—36	0·072	0·75	26	4·56	28	3·81	82	1·05	38	1·71	79	(0·79)	28	0·24	28	[2·75]
37—48	0·019	1·40	28	‡0·52	28	0·28	74	0·18	38	0·09	79	(0·44)	28	0·16	28	[0·67]
			Soil from Selkirk.													
1—12	0·618	3·94	28	48·13	28	34·77	87	58·83	35	24·90	79	(28·23)	28	21·73	49	17·39
13—24	0·264	3·08	28	‡13·67	28	22·74	77	26·61	35	11·30	79	(14·98)	28	13·61	49	15·06
25—36	0·076	0·52	28	0·99	28	1·86	71	1·08	35	0·45	79	(0·78)	28	0·27	28	[2·10]
37—48	0·042	0·31	28	0·19	28	0·22	62	0·77	38	0·35	79	(0·83)	28	0·23	28	[0·69]
			Soil from Winnipeg.													
1—12	0·428	132·37	28	38·09	28	28·85	88	57·75	35	35·03	79	(22·95)	28	21·23	49	28·26
13—24	0·327	83·19	28	‡5·95	28	24·75	85	24·27	38	17·97	79	(21·79)	28	3·95	49	17·74
25—36	0·158	36·02	28	12·40	28	17·64	77	7·94	40	12·02	79	(10·88)	28	2·14	28	[13·63]
37—48	0·107	11·52	28	5·70	28	8·16	57	0·72	45	4·03	79	(0·25)	28	0·55	28	[10·41]

* In the cases in which the results are given in parentheses, potassium phosphate, magnesium sulphate, and calcium carbonate were added to the soils after the 4th extraction.

† In the cases in which the figures are enclosed within brackets, thus [ ], the soils were seeded by 0·1 gram of garden soil after the 7th extraction; and the number of days given represents the period after seeding.

‡ Results probably low.

two or three times, and had grown very good crops of potatoes. It is unfortunate that the land had been manured, as an individual sample may, though there is no evidence that in this case it did, contain portions of undecomposed manure. Both the first and the second 12 inches of depth are very rich in nitrogen (0·428 and 0·327)—richer than the average of old pasture surface soils. The third depth is as rich as a good arable surface soil (0·158), and the fourth much richer than the Rothamsted second 9 inches (0·107).

To convey a more definite idea of the relative richness in nitrogen of these Manitoba prairie soils, it may be well to state that the nitrogen in the dry soil of the first 9 inches of depth of the arable soils at Rothamsted is sometimes as low as 0·1 and seldom exceeds 0·14 or 0·15 per cent.; that in the second 9 inches it ranges from 0·07 to little over 0·08 per cent.; in the third 9 inches from under 0·06 to about 0·07 per cent.; and that in the lower depths it is rather lower still. As a further indication of comparative fertility it may be added that old pasture land at Rothamsted contains in the first 9 inches from 0·25 to 0·30 per cent. of nitrogen.

Some soils, however, peaty soils for example, may contain a high percentage of nitrogen, but in such conditions as to be extremely slowly rendered available. What is the condition of the nitrogen of these rich prairie soils in this respect?

This is illustrated in the columns of the Tables showing the amounts of nitrogen as *nitric acid* found in these soils and subsoils, after exposure for successive periods under suitable conditions as to moisture and temperature. In Table V (p. 412), the quantities are calculated per million dry soil, for each period. In Table VI (p. 415), the amounts per million dry soil, per day, are given. In Table VII (p. 416), the percentage of the original nitrogen, which is nitrified within each period is given. Lastly, in Table VIII (p. 417), an approximate estimate is given of the amounts of *nitrogen nitrified* per acre, in each soil, at each depth, within each period, and during the total period of the experiments.

In the narrow columns of Table V, the number of days comprised in each period of exposure is recorded; some periods during which the samples were allowed to go and to remain dry, and the action thus arrested, not being included. It was at first intended that the periods should be uniformly 28 days; but owing to the pressure of other work it was impossible to adhere to this, and hence there are irregularities in the results, comparing period with period, in explanation of which the difference in the length of the periods must be taken into account; but they are also in part due to variations of temperature between period and period. On this point it may be stated that the temperature ranged over the several periods as follow:—

	Centigrade.
First period	15—24°
Second period	18—24
Third ,, ...	18—31
Fourth ,, ...	10—23
Fifth ,, ...	3·5—16
Sixth ,, ...	4—27
Seventh ,, ...	9—26
Eighth ,, ...	11—28

It will be seen that in the case of each set of soils the amount of nitrogen nitrified is very much the greater in the richer surface soil than in the poorer subsoils. It is also generally, though not uniformly, greater in the second than in the third, and in the third than in the fourth depth of 12 inches.

The results are, however, arranged in a more comparable form in Table VI, p. 415, which shows the average amount of nitrogen nitrified *per day*, per million of dry soil, over each period. It is there seen that in most cases, especially of the subsoils, the rate of nitrification was much less over the third and fourth than over the first and second periods.

As already said, after the fourth period, mineral consituents were added, but, from the results, obviously in excessive amount, so that over the fifth period there was scarcely any nitrification; and even taking the results of the fifth and sixth periods together, the rate does not appear to have been increased; whilst, over the seventh period compared with the fourth, it is in most cases, and in some of the subsoils, very much reduced. It will be observed that during parts of the fifth and sixth periods the temperature ranged low; but during the seventh period compared with the fourth, there was not much difference.

Lastly, the increase in the rate of nitrification over the eighth period compared with the seventh, in the case of the subsoils which had been seeded by the addition to them of only 0·1 gram of rich garden mould, is very great. These results are enclosed with brackets thus [ ].

The results as they stand are very striking; and assuming that their indications are not materially vitiated by the fact that some of the subsoils appear from their high amount of carbon to have contained particles of vegetable residue, they are of much interest and significance, affording evidence that the nitrogen of subsoils is subject to nitrification, provided only that the nitrifying organisms, and the other necessary conditions for nitrification, are not wanting.*

* Further experiments on the point are now in progress.

TABLE VI.

Manitoba Prairie Soils and Subsoils. Nitrogen Nitrified *per day* per million dry soil, during successive periods of exposure.

Depths.	Periods of exposure.							Average.
	1st.	2nd.	3rd.	4th.	5th and 6th.	7th.	8th.	
				Soil from Niverville.				
inches.								
1—12	0·513	0·337	0·526	lost	0·002	0·166	0·190	(0·250)
13—24	0·112	0·115	0·022	0·109	0·040	0·017	[0·238]	0·072
25—36	0·015	0·013	0·004	0·003	0·010	0·009	[0·046]	0·011
37—48	0·016	0·021	0·007	0·008	0·014	0·006	[0·023]	0·012
				Soil from Brandon.				
1—12	0·326	0·315	0·386	0·357	0·128	0·248	0·170	0·268
13—24	0·051	0·038	0·038	0·163	0·051	0·085	lost	(0·054)
25—36	0·175	0·136	0·013	0·045	0·010	0·009	[0·098]	0·048
37—48	0·019	0·010	0·002	0·002	0·006	0·006	[0·024]	0·008
				Soil from Selkirk.				
1—12	1·721	1·242	0·676	0·711	0·357	0·776	0·355	0·701
13—24	0·488	0·812	0·346	0·323	0·188	0·486	0·307	0·364
25—36	0·035	0·066	0·015	0·013	0·010	0·010	[0·075]	0·025
37—48	0·007	0·008	0·012	0·009	0·011	0·008	[0·025]	0·011
				Soil from Winnipeg.				
1—12	1·360	1·030	0·656	1·001	0·290	0·758	0·577	0·693
13—24	0·213	0·884	0·286	0·473	0·276	0·141	0·362	0·348
25—36	0·443	0·630	0·103	0·301	0·138	0·076	[0·487]	0·249
37—48	0·204	0·291	0·013	0·090	0·003	0·020	[0·372]	0·102

The results would thus lend confirmation to the view that, especially in the case of deep-rooted plants, the subsoil may become an important source of nitrogen yielded up to them as nitric acid; for, in addition to the channels formed by worms, such plants will form others by their roots, and by their growth will cause the passage upwards of much water, and so induce the passage downwards, not only of air, but of other matters, nitrifying organisms included.

Table VII, p. 416, shows the *percentage of the original nitrogen*, of the soils and subsoils, which was nitrified during each, and the total period of the experiments. The last column shows that, over the total period, from 4 to 5 per cent., or more, of the nitrogen of the richer soils and subsoils was so nitrified; but it is obvious that the conditions of these experiments cannot be compared with those of the soils in their natural conditions of exposure, moisture, and temperature.

TABLE VII.

Manitoba Prairie Soils and Subsoils. Percentage of original Nitrogen Nitrified during successive periods of exposure.

Depths.	Periods of exposure.							Total.
	1st.	2nd.	3rd.	4th.	5th and 6th.	7th.	8th.	
Soil from Niverville.								
inches.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
1—12	0·55	0·36	1·75	lost	0·01	0·18	0·36	(3·21)
13—24	0·11	0·19	0·11	0·24	0·19	0·03	[0·39]	1·26
25—36	0·06	0·05	0·05	0·02	0·11	0·03	[0·19]	0·51
37—48	0·12	0·16	0·13	0·08	0·29	0·05	[0·17]	1·00
Soil from Brandon.								
1—12	0·49	0·47	1·79	0·67	0·54	0·37	0·45	4·78
13—24	0·13	0·10	0·30	0·52	0·37	0·22	lost	(1·64)
25—36	0·63	0·53	0·15	0·24	0·11	0·03	[0·38]	2·07
37—48	0·27	0·15	0·09	0·05	0·23	0·08	[0·35]	1·22
Soil from Selkirk.								
1—12	0·78	0·56	0·95	0·40	0·45	0·35	0·28	3·77
13—24	0·52	0·86	1·01	0·43	0·57	0·52	0·57	4·48
25—36	0·13	0·25	0·14	0·06	0·10	0·04	[0·28]	1·00
37—48	0·05	0·05	0·18	0·08	0·20	0·05	[0·16]	0·77
Soil from Winnipeg.								
1—12	0·89	0·67	1·35	0·82	0·53	0·50	0·66	5·42
13—24	0·18	0·76	0·74	0·55	0·66	0·12	0·54	3·55
25—36	0·78	1·12	0·50	0·76	0·69	0·14	[0·86]	4·85
37—48	0·53	0·76	0·07	0·38	0·02	0·05	[0·97]	2·78

For the same reason, the calculations *per acre*, given in Table VIII, must also be accepted with much reservation. Still the results are

TABLE VIII.

Manitoba Prairie Soils and Subsoils. Estimated Amounts of Total Nitrogen, and of Nitrogen Nitrified, *per acre*, during successive periods of exposure.

Depths.	Total nitrogen per acre.	Nitrogen as nitric acid. Periods of exposure. 1st.	2nd.	3rd.	4th.	5th & 6th.	7th.	8th.	Total.
		Soil from Niverville.							
inches.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1—12	7,308	40·1	26·4	128·1	lost	0·04	13·0	26·1	(234·1)
13—24	5,408	10·0	10·3	6·1	13·3	10·1	1·8	[21·3]	72·9
25—36	2,484	1·4	1·3	1·2	0·4	2·8	0·9	[4·6]	12·6
37—48	1,520	1·8	2·4	2·0	1·2	4·4	0·7	[2·5]	15·0
		Soil from Brandon.							
1—12	5,236	25·6	24·7	93·9	35·0	28·4	19·4	23·4	250·4
13—24	3,488	4·6	3·4	10·5	18·2	12·9	7·6	lost	(57·2)
25—36	2,592	16·4	13·7	3·8	6·2	2·8	0·9	[9·9]	53·7
37—48	870	2·4	1·3	0·8	0·4	2·0	0·7	[3·1]	10·7
		Soil from Selkirk.							
1—12	17,304	134·8	97·4	164·7	69·7	79·0	60·8	48·7	655·1
13—24	8,448	43·7	72·8	85·2	36·2	47·9	43·5	48·2	377·5
25—36	2,736	3·6	6·7	3·9	1·6	2·8	1·0	[7·6]	27·2
37—48	1,487	0·7	0·8	2·7	1·2	2·9	0·8	[2·4]	11·5
		Soil from Winnipeg.							
1—12	11,984	106·6	80·8	161·7	98·1	64·3	59·4	79·1	650·0
13—24	10,464	19·0	79·2	77·7	57·5	69·7	12·6	56·8	372·5
25—36	5,688	44·6	63·5	28·6	43·3	39·2	7·7	[49·1]	276·0
37—48	4,045	21·6	30·8	2·7	15·2	1·0	2·1	[39·4]	112·8

not without significance, as conveying an idea of how freely these soils will yield up their nitrogen in an available form, when subjected to favourable conditions of cultivation, and of drainage if need be, favouring aëration, with, at the same time, suitable moisture and temperature. It must be borne in mind, however, that this ready susceptibility to oxidation of the nitrogen is a source of loss rather than of gain, if the nitrates are not taken up by crops, but are allowed to encourage the growth of weeds, or to be lost by drainage.

It should be added that qualitative examinations lead to the conclusion that these soils are not deficient in the necessary mineral constituents.* They are, in fact, virgin soils of great fertility, accumulated by ages of natural vegetation, with little or no removal. There is abundant evidence that they are capable of yielding large crops; but that, under present conditions, they do not, on the average, yield amounts of produce at all commensurate with their richness compared with the soils of Great Britain which have been under arable cultivation for centuries, there can be no doubt; for, according to official records, their average yield of wheat per acre is even considerably less than that of the United Kingdom.

That the rich prairie soils of the North-west do not yield higher amounts of produce than they do, is due in part to vicissitudes of climate, and to short seasons of growth, but largely to scarcity of labour, and consequent imperfect cultivation, leading, with other disadvantages, to a luxuriant growth of weeds. Then, again, in the early years of settlement, and until mixed agriculture and stock feeding can be had recourse to, and local demand arises, the burning of the straw, and the deficient production, or the disregard and waste, of manure, are more or less unavoidable, but nevertheless very exhausting practices. So long as land is cheap, and labour dear, some sacrifice of fertility is inevitable in the process of bringing these virgin soils under profitable cultivation; and the only remedy is to be found in increase of population. Still, the fact should not be lost sight of, that such practices of early settlement do involve a serious waste of fertility.

It will be of interest here to contrast the condition of soils of very different history, as to their percentages of nitrogen, and so far as we are able, of carbon also.

Table IX, p. 419, shows the characters, in these respects, of exhausted arable soils, of newly laid down pasture, and of old pasture soils, at Rothamsted, of some other old arable soils, of some Illinois and Manitoba prairie soils, and, lastly, of some very rich Russian soils.

From these results there can be no doubt, that a characteristic of a rich virgin soil, or of a permanent pasture surface soil, is a relatively high percentage of nitrogen and of carbon, and a high relation of carbon to nitrogen. On the other hand, a soil that has long been in arable culture is much poorer in these respects; whilst an arable soil under con-

* See reference to Dr. Voelcker's analyses of Illinois prairie-soil, p. 409; also an analysis of a Manitoba prairie-soil, by Dr. J. M. H. Munro, *Chem. News*, April 2, 1885.

TABLE IX.

Nitrogen and Carbon in Various Soils.

	Date of soil sampling.	In dry sifted soil.* Nitrogen.	Carbon.	Carbon to 1 nitrogen.	Authority.
Rothamsted Arable and Grass Soils.					
		Per cent.	Per cent.	Per cent.	
Roots 1843–52; barley 1853–55; Roots 1856–69; mineral manures	April 1870	0·0934	—	—	Rothamsted.
Wheat 1843–44, and each year since; mineral manures	Oct. 1865	0·1119	1·039	9·3	,,
	Oct. 1881	0·1012	1·079	10·7	,,
Barley 1852, and each year since; mineral manures...	Mar. 1868	0·1202	—	—	,,
	Mar. 1882	0·1124	1·154	10·3	,,
Arable laid down to grass (ten acres), spring 1879	Feb. 1882	0·1235	—	—	,,
(Barnfield), spring 1874	Feb. 1882	0·1509	—	—	,,
(Appletree field), spring 1863	Nov. 1881	0·1740	—	—	,,
(Dr. Gilbert's meadow), spring 1858	Jan. 1879	0·2057	2·412	11·7	,,
(Highfield), spring (?) 1838	Sept 1878	0·1943	2·403	12·4	,,
Very old grass land (The Park)	Feb. and Mar. 1876	0·2466	3·377	13·7	,,
Various Arable Soils in Great Britain.					
Mr. Prout's farm, Broadfield, surface	—	0·170	—	—	Voelcker.
,, Blackacre ,,	—	0·107	—	—	,,
,, Whitemoor ,,	—	0·171	—	—	,,
Wheat soil, Midlothian	—	0·22	—	—	Anderson.
,, Eastlothian	—	0·13	—	—	,,
,, Perthshire	—	0·21	—	—	,,
,, Berwickshire	—	0·14	—	—	,,
Red sandstone soil, England	—	0·18	—	—	Voelcker.
United States and Canadian Prairie Soils.					
Illinois, U.S. No. 1	—	0·30	—	—	Voelcker.
,, ,, No. 2	—	0·26	—	—	,,
,, ,, No. 3	—	0·33	—	—	,,
,, ,, No. 4	—	0·34	—	—	,,
Portage la Prairie, Manitoba, surface	—	0·247	—	—	Rothamsted.
Saskatchewan district, N.W. territory, surface	—	0·303	—	—	,,
40 miles from Fort Ellice, N.W. territory ,,	—	0·250	—	—	,,
Niverville, Manitoba, 1st 12 inches	—	0·261	3·42	13·1	,,
Brandon, ,, ,,	—	0·187	2·66	14·2	,,
Selkirk, ,, ,,	—	0·618	7·58	12·3	,,
Winnipeg, ,, ,,	—	0·428	5·21	12·2	,,
Russian Soils.					
No. 1, 12 inches	—	0·607	—	—	C. Schmidt.
No. 2, 8 ,,	—	0·467	—	—	,,
No. 3, 5 ,,	—	0·188	—	—	,,
No. 4, 6 ,,	—	0·130	—	—	,,
No. 5, 11 ,,	—	0·305	—	—	,,
No. 6, 17 ,,	—	0·281	—	—	,,
No. 7, 9 ,,	—	0·409	—	—	,,

* Calculated on soil dried at 100° C.

ditions of known agricultural exhaustion shows very low percentages of nitrogen and carbon, and a low relation of carbon to nitrogen.

In conclusion, it has been maintained by some that a soil is a laboratory and not a mine, but not only the facts adduced in this and in former papers, but the history of agriculture throughout the world, so far as it is known, clearly show that a fertile soil is one which has accumulated within it the residue of ages of previous vegetation, and that it becomes infertile as this residue is exhausted.

Summary and Conclusions.

1. The annual yield of nitrogen per acre in various crops, grown for many years in succession on the same land without nitrogenous manure, was found to be very much greater than the amount of combined nitrogen annually coming down in rain and the minor measurable aqueous deposits.

2. So far as the evidence at command enables us to judge, other supplies of combined nitrogen from the atmosphere, either to the soil or to the plant itself, are quite inadequate to make up the deficiency.

3. The experimental evidence as to whether plants assimilate the free nitrogen of the atmosphere is very conflicting; but the balance is decidedly against the supposition that they so derive any portion of their nitrogen.

4. When crops are grown year after year on the same land, for many years in succession without nitrogenous manure, both the amount of produce per acre, and the amount of nitrogen in it, decline in a very marked degree. This is the case even when a full mineral manure is applied; and it is the case not only with cereals and with root-crops, but also with *Leguminosæ*.

5. Determinations of nitrogen in the soils show that, coincidently with the decline in the annual yield of nitrogen per acre of these very various descriptions of plant, grown without nitrogenous manure, there is also a decline in the stock of nitrogen in the soil. Thus a soil-source, of at any rate some, of the nitrogen of the crops is indicated. Other evidence pointed in the same direction.

6. Determinations of the nitrogen as nitric acid, in soils of known history as to manuring and cropping, and to a considerable depth, showed that the amount of nitrogen in the soil in that form was much less after the growth of a crop than under corresponding conditions without a crop. This was the case not only with gramineous but with leguminous crops. It was hence concluded that nitrogen had been taken up as nitric acid by the growing crops.

7. In the case of gramineous crop-soils, the evidence pointed to the conclusion that most, if not the whole, of the nitrogen of the crops was taken up as nitric acid from the soil.

8. In the experiments with leguminous crop-soils, it was clear that some at any rate of the nitrogen had been taken up as nitric acid. In some cases, the evidence was in favour of the supposition that the whole of the nitrogen had been so taken up. In others this seemed doubtful.

9. Although in the growth of leguminous crops year after year on the same land without nitrogenous manure, the crop, the yield of nitrogen in it, and the total nitrogen in the surface soil, greatly decline, yet, on the substitution of another plant of the same family, with different root-habit and root-range, large crops, containing large amounts of nitrogen, may be grown. Further, in the case of the occasional growth of a leguminous crop, red clover for example, after a number of cereal and other crops, manured in the ordinary way, not only may there be a very large amount of nitrogen in the crop, presumably derived from the subsoil, but the surface soil becomes determinably richer in nitrogen, due to crop-residue.

10. It was found that, under otherwise parallel conditions, there was very much more nitrogen as nitric acid, in soils and subsoils down to a depth of 108 inches, where leguminous than where gramineous crops had grown. The results pointed to the conclusion that, under the influence of leguminous growth and crop-residue, the conditions were more favourable for the development of the nitrifying organisms, and, especially in the case of deep-rooting plants, of their distribution, thus favouring the nitrification of the nitrogen of the subsoil, which so becomes a source of the nitrogen of such crops.

11. An alternative was that the plants might take up at any rate part of their nitrogen from the soil and subsoil as organic nitrogen. Direct experimental evidence leads to the conclusion that fungi take up both organic nitrogen and organic carbon, but there is at present no direct experimental evidence in favour of the view that green-leaved plants take up either nitrogen or carbon in that form from the soil; whilst there are physiological considerations which seem to militate against such a view.

12. In the case of plots where *Trifolium repens* and *Vicia sativa* had been sown, each for several years in succession, on soil to which no nitrogenous manure had been applied for about 30 years, and the surface soil had become very poor in nitrogen, both the soil and subsoil contained much less nitrogen as nitric acid where good crops of *Vicia sativa* had grown, than where the more shallow-rooted *Trifolium repens* had failed to grow; and the deficiency of nitric nitrogen in the soils and subsoils of the *Vicia sativa* plots, compared with the amount in those of the *Trifolium repens* plot, was, to the depth examined, sufficient to account for a large proportion of the nitrogen of the *Vicia* crops.

13. It may be considered established, that much, if not the whole, of the nitrogen of crops is derived from nitrogen within the soil—accumulated or supplied; and that much, and in some cases the whole, of the nitrogen so derived, is taken up as nitrates.

14. An examination of a number of United States and Canadian prairie soils showed them to be very much richer in both nitrogen and carbon, to a considerable depth, than the surface soil of old arable lands in Great Britain, and about as rich, to a much greater depth, as the surface soil of permanent pasture land.

15. On exposure of portions of some of these rich prairie soils, under suitable conditions of temperature and moisture, for specified periods, it was found that their nitrogen was readily susceptible of nitrification, and so of becoming easily available to vegetation.

16. After several extractions, the subsoils almost ceased to give up nitric acid; but on seeding them with a tenth of a gram of rich garden soil containing nitrifying organisms, there was a marked increase in the rate of nitrification. This result afforded confirmation of the view that the nitrogen of subsoils is subject to nitrification, if under suitable conditions, and that the growth of deep-rooted plants may favour nitrification in the lower layers.

17. Under favourable conditions of season and of cultivation, the rich prairie soils yield large crops; but, under the existing conditions of early settlement, they do not, on the average, yield crops at all commensurate with their richness, when compared with the soils of Great Britain which have been under arable culture for centuries. But so long as the land is cheap, and labour dear, some sacrifice of fertility is unavoidable in the process of bringing these rich virgin soils under profitable cultivation.

18. A comparison of the percentages of nitrogen and carbon in various soils of known history, showed that a characteristic of a rich virgin soil, or of a permanent pasture surface soil, was a relatively high percentage of nitrogen and carbon. On the other hand, soils which have long been under arable culture are much poorer in these respects; whilst arable soils under conditions of known agricultural exhaustion, show a very low percentage of nitrogen and carbon, and a low proportion of carbon to nitrogen.

19. Not only the facts adduced in this and in former papers, but the history of agriculture throughout the world, so far as it is known, clearly show that, pre-eminently so far as the nitrogen is concerned, a fertile soil is one which has accumulated within it the residue of ages of natural vegetation, and that it becomes infertile as this residue is exhausted.