XXXI.—*Contribution to the Chemistry of "Fairy Rings."*

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THE circles of dark-green grass which frequently occur on pasture land, and have long been known by the name of "Fairy Rings," have naturally attracted the attention of botanists and vegetable physiologists, and various explanations of their occurrence have been given. It has long been supposed that the luxuriant growth of grass constituting the ring is connected with the growth and decay of fungi, which so serve as manure for the grasses which succeed them. Among the numerous explanations of the fact that the growth assumes the form of an extending ring, perhaps the one which for some time received the greatest attention, was that based on the theory of Decandolle, according to which the excretions of a plant are prejudicial to the growth of plants of the same description. It was supposed that the excretions of fungi were detrimental to their recurrence on the same spot, and hence they developed only externally to the ring of their previous growth.

The first explanation of the luxuriant growth of the rings, put forward from a more purely chemical point of view, was that of Professor Way, in a paper "On the Fairy Rings of Pasture, as illustrating the use of Inorganic Manures," which was read in the Chemical Section of the British Association at Southampton in 1846, and was published in the *Journal of the Royal Agricultural Society of England*, 7, 549. He analysed the ash of some of the fungi, and also of the grass of a fairy ring. From the results of these analyses he explains the growth of the fairy rings as follows:—"A fungus is developed on a single spot of ground, sheds its seed, and dies. On the spot where it grew it leaves a valuable manuring of phosphoric acid and alkalis, some magnesia, and a little sulphate of lime. Another fungus might undoubtedly grow on the same spot again; but upon the death of the first the ground becomes occupied by a vigorous crop of grass, rising like a phoenix, on the *ashes* of its predecessor." The growth of the grass as an extending ring, and not as a disc, he further explains by the fact of the removal of the grass, and with it "the greater part of the inorganic materials which the fungus had collected." He adds, that the nitrogen of the fungus must not be left out of consideration, but that he believes—"it is to the inorganic elements that the effect is chiefly to be ascribed."

Buckman, on the other hand, whilst admitting that fungi are fre-

quently found on or just outside the ring, considers their occurrence by no means essential to the formation of the ring, and that it may be produced by any cause unfavourable to the growth of a circular disc of grass. At the same time he says—"there is reason to think that rings to which the fungi have not become attached soon break up" (*Veterinarian*, May and June, 1870).

Almost from the commencement of the Rothamsted experiments, the circumstances of the development of fairy rings have been observed with much interest, as affording a striking example of what may be called "natural rotation." It was thought that if the source of the nitrogen of the fungi growing in fairy rings were determined, some light might perhaps be thrown on the source of the nitrogen of the Leguminosæ, which are grown separately, in rotation with the cereals and other crops, or in association with the grasses in the mixed herbage of grass land. In a Rothamsted paper in 1851 (*Jour. Roy. Ag. Soc.*, 12, 32), the subject was referred to as follows:—"A beautiful illustration of the dependence for luxuriant growth of one plant upon another of different habits, such as we have shown above, may be found in the case of the 'fairy rings,' where the fungus, by virtue of its extraordinary power of rapidly accumulating nitrogen from the atmosphere during its growth, taking up the minerals which the grasses, from their more limited power in this respect could not appropriate, provides an abundance of the nitrogenous manure so effective in the growth of the grasses which are observed to spring up with great luxuriance wherever the fungus has grown or fallen."

Here, then, it was assumed that it was the nitrogen, rather than the ash-constituents of the fungus, to which the manuring action was mainly to be attributed. Even at that time the characteristic effects of mineral and nitrogenous manures respectively, on the growth of gramineous crops, were sufficiently established by field experiments to leave no doubt that the dark colour and the luxuriant growth of the grasses on the rings were intimately connected with a liberal supply of nitrogen as manure. But it will be observed that the source of the nitrogen of the fungi was then supposed to be the atmosphere.

Since that time much directly experimental and other evidence has been acquired as to the sources of the nitrogen of green-leaved plants; and, although absolute proof is still wanting on some points—and it might well be that plants of such opposite characters as fungi might have a different source—yet doubt as to the atmospheric source of their nitrogen gradually increased. Accordingly, in 1874, an attempt was made to obtain direct experimental data on the subject. Samples of soil were taken of a fixed area and to a fixed depth within, on, and outside a fairy ring; and in each the nitrogen was determined.

The results showed the lowest percentage of nitrogen in the surface soil within the ring, a higher percentage under the ring, and a higher still outside it. The obvious conclusion was, that the soil within the ring had lost nitrogen by the growth of the fungi, and the subsequent luxuriant growth and removal of the grasses. But so important a conclusion required confirmation. Accordingly, in a short paper by one of us entitled "Note on the Occurrence of Fairy Rings," published in 1875 (*Jour. Linn. Soc. Bot.*, 15, 17), the general indication only was stated, reserving the publication of the numerical results until they should be confirmed. The soils of other fairy rings have since been collected and investigated, and it was intended to extend the inquiry further; but, owing to the unfavourable weather of the last few years, the rings which had been under examination have disappeared. Under these circumstances, and as the general bearing of the results already obtained is unmistakable, it has been decided to put on record both the earlier and the later results, without waiting for further repetition or extension.

Before entering upon a consideration of the experimental results in question, it will be well to refer a little more in detail to some of the circumstances of the occurrence of a fairy ring.

It is probable that the fungi growing on grass land owe their occurrence, in the first instance, to the accidental droppings of animals (or birds); and it seems to depend on the conditions of soil, season, and association, whether the growth is limited to the original spot, or whether it extends, and an annually increasing ring is formed. If the soil be rich, or highly manured, or the season very favourable for luxuriance of the general herbage, the probability is that the fungi will not be reproduced, and a patch only will be developed. It is under opposite conditions, that is, where the soil is poor, that the development of rings is generally observed.

The growth of fungi being once established from some extraneous cause, such as above referred to, they will on decay supply a rich nitrogenous and mineral manuring to the adjacent herbage. A patch of dark-green luxuriant grass succeeds. This being cut or eaten off, the soil becomes the more exhausted the more luxuriant has been the growth. Accordingly the vegetation within the ring is generally less luxuriant than that outside it. In the case of mere patches, some examinations of the soil in spring and autumn have not shown a marked development of mycelium. But on digging into the turf immediately outside a ring, it is generally found penetrated by a white cobweb-like mycelium, extending to a depth of several inches, and sometimes even to a foot or more. When the mycelium is abundant, the soil is remarkably dry, and can with difficulty be wetted, as if it were greasy. The mycelium is most abundant in the soil

just outside the ring, or at the outer edge of it. If the season be favourable, an aboveground growth of fungi will appear in the spring or autumn. These fructify, and, by scattering their spores, give rise to a further growth of mycelium. The fungus thus spreads into fresh ground, and the rings extend outwards, so long as the circumstances of the soil and season are favourable. Sometimes, however, fungi are found growing in the midst of the band of luxuriant grass. In such cases it would appear that the increased growth of the grass is due to the decay of the mycelium, or to its action on some of the organic compounds in the soil.

In the paper above referred to, the relative development of fairy rings, and of fungi generally, on the differently manured plots of meadow land in the park at Rothamsted is described. Among the more than twenty differently manured plots, fairy rings have occurred on only two, neither of which has received either nitrogen or potash as manure for many years. The one is annually manured with superphosphate of lime alone, and the other with a mixture of superphosphate and the sulphates of sodium and magnesium. Quite consistently with what is commonly recognised as to the conditions most favourable for the development of fairy rings, the general vegetation on these plots is of a very restricted character. Where nitrogenous manures are applied, and the luxuriant growth of the grasses is thereby promoted, no fairy rings have occurred, and the appearance of fungi is rare. As fairy rings thus developed only where the growth of the grasses and their associates was extremely limited (owing to deficient supply of nitrogen or of potash, or of both, in a condition available to them), the questions were suggested—How far the fungi prevail simply in virtue of the absence of adverse and vigorous competition?—whether they live to a greater or less extent as parasites, and so at the expense of the sluggish underground growth of the plants in association with them?—whether they have the power of acquiring nitrogen in some form from the atmosphere?—or, lastly, whether they assimilate nitrogen from the soil itself, existing there in a condition not available to the plants growing in association with them?

Of the composition of the mycelium but little is known, and it is to be supposed that it would vary considerably at different periods of its development. On several occasions it has been found at Rothamsted to leave a very considerable incombustible residue, consisting chiefly of calcium carbonate, which is presumably the result of the destruction of calcium oxalate.

The general composition of the aboveground growth has been determined by Fleury in the case of two of the fairy ring fungi (*Rép. Pharm.*, 31, ann. 73, p. 261). The following is an abstract of his results:—

TABLE I.—Percentage Composition of two Fairy Ring Fungi.

Species.	Water.	Nitrogen reckoned as albu- minoids.	Fatty matter.	Soluble carbo- hydrates.	Fibre.	Ash.
<i>In Fresh Substance.</i>						
<i>Marasmius oreadam</i>	91·75	2·93	0·19	3·59	0·67	0·87
<i>Agaricus prunulus..</i>	89·25	4·11	0·14	4·08	0·81	1·61
<i>In Dry Matter.</i>						
<i>Marasmius oreadam</i>	—	35·57	2·40	43·34	8·12	10·57
<i>Agaricus prunulus..</i>	—	38·32	1·38	37·77	7·53	15·00

The following is the composition of the ash of one species of fairy-ring fungus as determined by Professor Way (*Jour. Roy. Ag. Soc.*, 7, 550, 1846):—

TABLE II.—Percentage Composition of the Ash of *Agaricus prunulus*.

Ash in 100 dry.	Per cent. in Ash.								
	K ₂ O.	Na ₂ O.	CaO.	MgO.	P ₂ O ₅ .	SO ₃ .	SiO ₂ .	Cl.	CO ₂ .
6·38	55·10	3·54	1·35	2·20	29·49	1·93	1·09	0·25	3·80

The composition of the fairy ring fungi appears from these analyses to be very similar to that of other fungi which have been analysed; and it may be mentioned that one of the species examined by Fleury, the *Marasmius oreadam*, occurs on the rings at Rothamsted. The fungi contain a large proportion of nitrogenous matter, amounting to more than one-third of their dry substance; and their ash is extremely rich in both potash and phosphoric acid, but especially in potash. Yet it will be remembered that fairy rings developed only on two of the experimental plots at Rothamsted, neither of which had received either nitrogen or potash as manure for many years, and where the growth of the grasses was extremely meagre.

It is evident from the very restricted vegetation of these plots, from the richness in nitrogen of the fungi, and from the great luxuriance of the grasses which succeed them, that the fungi were

able to obtain an amount of nitrogen from some source greatly in excess of that which was available to the associated herbage. What is the source of this nitrogen? Has the fungus the power of assimilating it largely from the atmosphere? or has it the power of taking it up from the soil in a manner, or in a degree, which the grasses and other green-leaved plants do not possess? The object of the experiments now to be described was to obtain an answer to these questions.

We will first give a brief history of the various samples of soil which have been collected and analysed, and afterwards direct attention to the results which have been obtained.

The Grove Paddock Fairy Ring.

The samples of soil were taken on May 19th, 1874. The ring, which then consisted of a half circle several yards in diameter, and had been observed to increase during the past few years, was near a hedge and some trees, and the soil was much permeated by roots. The band of grass forming the ring was about 2 feet wide, and of a dark bluish-green colour. The grass was of a much lighter colour both within and outside the ring, and rather lighter within than outside. Samples of the soil were taken at three points: 1. Two feet within the ring. 2. In the centre of the ring-band. 3. Two feet outside the ring. In each case a sample of the first, and of the second 9 inches of depth, was taken.

The mode of collecting the soil samples was that which has been employed for many years at Rothamsted. A frame of strong sheet iron 6 inches square, 9 inches deep, open at the top and bottom, and having a strong rim outside the upper edge, was driven into the ground until the upper edge was level with the surface. The contents were then carefully taken out, and constituted the sample of the first 9 inches of depth. The soil round the frame was then removed to the depth of its lower edge, it was again driven down into the soil, and the contents taken out, these representing the second 9 inches of depth.

The sample of the first 9 inches of soil taken on the ring was remarkably dry, and much paler in colour than that of the sample from the same depth either from without or within the ring, that from outside the ring being much the darkest of the three. Mycelium was found to extend to the depth of a foot or more. This is a somewhat greater depth than usual, probably accounted for by the large amount of organic *débris* from the roots of the hedge, and two large ash trees, one on either side.

The Broadbalk Field Fairy Ring.

This was a small imperfect ring forming about two-thirds of a

circle. The ground within the circle had been disturbed in recent years, and there was doubt how far the disturbance had extended.

The first series of samples was taken on June 18th, 1877. The ring was then covered with a luxuriant growth of grass, interspersed with which were a few fungi. The samples of soil taken were: 1. Within the ring, about 14 inches from it. 2. On the ring. 3. Just outside the ring. 4. Quite outside it, about 16 inches from it. A rather considerable amount of mycelium was found in the soil taken from the ring, extending from the surface to a depth of 5 or 6 inches. In the sample taken just outside the circle a little mycelium was found.

A second series of samples was taken on September 15th of the same year. The ring had widened since June, and was again covered with a luxuriant growth of grass. The samples taken were: 1. Within the ring, 18 inches from it. 2. On the ring. 3. Outside the ring, about 15 inches from it. The soil from the ring contained a comparatively small amount of mycelium, extending about 4 inches from the surface.

The samples of soil from this ring, and from those subsequently experimented upon, were not taken with the iron frame already described, but with a steel cylinder, $2\frac{1}{2}$ inches in diameter, and 12 inches long, fixed at the end of a stout iron rod. The cylinder was driven into the ground until its upper edge was level with the surface; when withdrawn it contained a solid core of soil, which was removed through a slit in the side which was covered during the working. The advantage of this mode of soil sampling is its simplicity; but the objections to it are that the quantities of soil brought up are more irregular, and do not therefore so nearly represent the depth intended as when the wider square frame is used. Owing to the narrowness of the cylinder the soil rises within it with considerable difficulty, becoming much consolidated below, and when the cylinder is drawn up it is found to be but partially filled. In any case, however, it would be inappropriate to calculate quantities of soil, or of any of its constituents, over a given area to a given depth, from single samples; and as the object in the present instance was simply to compare the percentage composition of different samples of soil collected at the same time and in the same manner, the imperfections of the method above referred to are of less consequence.

The Park Fairy Rings.

It has been already mentioned that fairy rings were numerous on the plot of experimental meadow land in the park which was continuously manured with superphosphate of lime alone. A perfect ring on this plot was selected for examination. The samples of soil

were taken on September 19th, 1877. The band of grass forming the ring was about 3 feet wide, and very luxuriant, but no aboveground growth of fungi was then observed. The samples taken were: 1. Within the ring, about 4 feet from the centre of the band. 2. On the ring, in the middle of the band. 3. On the ring, at its outer edge. 4. Quite outside the ring. In the soil from the centre of the band but little mycelium was found; in that from the outer edge, mycelium was abundant at the surface, but extended very little below it.

In the following spring (1878) this ring having extended considerably in width, and its outline having become indistinct, no further samples were taken from it; but another partial ring on the same plot was selected for experiment. The soil of this second ring was sampled on April 25th, 1878. The band was then about 2 feet wide. The samples taken were: 1. Within the ring, about $2\frac{1}{2}$ feet from it. 2. On the ring towards the inside. 3. On the ring towards the outside. 4. Outside the ring, about $1\frac{1}{2}$ foot from it. In the soil taken from the ring towards the outside of it, mycelium was fairly developed, and extended 5 or 6 inches below the surface. Here the soil was drier, and of a lighter colour, than at the other points.

Preparation and Analysis of the Soil Samples.

From all the samples, the stones, roots, and other observable organic residue were carefully picked out, and the remaining soil was reduced to fine powder. The samples from the Broadbalk Field and the Park Fairy Rings were partially dried by exposure in a thin layer in a warm room immediately after being received in the laboratory; but those from the Grove Paddock were not so prepared. As a necessary means of calculation, especially of the percentage of water, the weights of the fresh samples, and of their separated parts, were taken in all cases excepting those of the soils from the Broadbalk Field.

The following table shows the percentage of water, lost on drying at 100° C., and calculated on the total fresh soil (excluding stones), in the cases of all the samples from the Grove Paddock, and the Park Fairy Rings.

TABLE III.—*Percentage of Water in Fresh Soil as collected, exclusive of Stones.*

	Surface soil.	Subsoil.
<i>Grove Paddock Fairy Ring Soils, May 19, 1874.</i>		
Within the ring.....	16·03	15·68
On the ring	12·58	12·30
Outside the ring	15·71	16·24
<i>The Park Fairy Ring Soils, September 19, 1877.</i>		
Within the ring.....	22·80	17·04
On ring (centre)	19·29	13·13
On ring (outer edge)	18·50	13·23
Just outside ring	23·33	15·03
<i>The Park Fairy Ring Soils, April 25, 1878.</i>		
Within the ring.....	26·34	19·21
On ring (inside)	26·33	—
On ring (outside)	21·95	19·14
Outside the ring	27·96	19·74

It will be observed that the percentage of water is almost uniformly lower in the soils taken from the ring-band than in those taken either within or outside it; and this generally holds good in the case of the subsoils as well as of the surface soils. The comparative dryness of the soil under the ring-band will in part be due to the greater evaporation incident to the greater activity of growth; but, in some cases, as in that of the Grove Paddock Ring, it is probably to be largely attributed to the action of the underground fungoid growth in giving to the soil, in some way not quite explicable, a power of resisting the free absorption of water, as if it were greasy, as already referred to.

In all the surface soils the nitrogen has been determined by combustion with soda-lime, and the carbon by combustion in oxygen; and in those from the Broadbalk Field and the Park Fairy Rings the nitrogen as nitric acid has also been determined. The subsoils have only been partially examined, and such determinations of nitrogen as have been made in them by the soda-lime method indicate that the variations in the amount are due to differences in the character of the subsoils, quite independent of the influences of the growth of the

fungi, and of the grasses succeeding them, which are the subjects of the present inquiry. Indeed, very numerous determinations of nitrogen in subsoils have shown that, with a low actual percentage, the variations in the amount in different samples are proportionally great, and obviously to a great extent unconnected with the special history of the plot from which the samples are taken. Moreover, so far as the total nitrogen and carbon are concerned, it seems probable that the influences of the fairy ring growth are, to a great extent, if not wholly, limited to the surface soils; and it will be seen that the results relating to them afford conclusive evidence on the points under inquiry.

In Table IV are given the percentages of nitrogen and carbon in the dry fine surface soils (that is excluding stones, roots, and water).

TABLE IV.—*Percentages of Nitrogen and Carbon in the Dry Fine Surface Soils.*

	Nitrogen.	Carbon.
<i>Grove Paddock Fairy Ring Soils, May 19, 1874.</i>		
Within the ring	0·262	3·06
On the ring	0·274	(2·72)*
Outside the ring	0·287	3·34
<i>Broadbalk Field Fairy Ring Soils, June 18, 1877.</i>		
Within the ring	0·271	2·38
On the ring	0·300	3·36
Just outside the ring	0·327	3·05
Quite outside the ring	0·303	3·52
<i>Broadbalk Field Fairy Ring Soils, September 15, 1877.</i>		
Within the ring	0·226	2·48
On the ring	0·244	2·60
Outside the ring	0·274	3·12

* In the Grove Paddock soils the carbon was not determined until some years after the collection, when the sample taken on the ring was found to have a high percentage of water, and a mouldy odour; it had doubtless lost carbon.

	Nitrogen.	Carbon.
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The Park Fairy Ring Soils, September 19, 1877.

Within the ring	0·222	2·88
On the ring (centre)	0·230	3·01
On the ring (outer edge)	0·276	3·40
Just outside the ring	0·259	3·31

The Park Fairy Ring Soils, April 25, 1878.

Within the ring	0·253	3·12
On the ring (inner side)	0·245	2·97
On the ring (outer side)	0·268	3·11
Outside the ring	0·269	3·44

Although, as has been said, all visible organic *débris* was carefully removed from the samples before nitrogen and carbon were determined in them, it will be readily understood that in the case of surface soils of grass land containing so much of such matter, it is extremely difficult to exclude the whole of it, whilst any irregularity in this respect will affect the amount of carbon more than that of the nitrogen; and a consideration of the results in detail leads to the conclusion that the carbon determinations are, from this cause, less trustworthy than those of the nitrogen. Still a glance at the Table (IV) shows that in each of the five series of samples the percentage of both nitrogen and carbon is much lower in the soils within the ring than outside it; that is to say, it is much lower where the action of the fungus and the growth and removal of the luxuriant crop of grass is past, than where the fungus has not yet been developed. In most cases where the action of the fungus is still in progress, the percentages of nitrogen and carbon are intermediate between those in the soils within and without the circle. The spread of the ring is in fact marked by a destruction of organic matter containing nitrogen and carbon.

It will be observed, however, that there are some apparent anomalies in the results, but on an examination of the circumstances of the experiments, these are sufficiently explained. Thus, the percentages of both nitrogen and carbon are much higher in the series of samples collected from the Broadbalk Field Fairy Ring in June, 1877, than in those collected from the same ring in the following September; and according to notes taken at the time, the sampling cylinder did not bring up so much soil in June as in September. In other words,

the samples taken in June comprised a larger proportion of the surface, and a smaller proportion of the subsoil, and hence the higher range in the percentage of nitrogen and carbon in them. Again, the percentages of both nitrogen and carbon are abnormally high in the sample from the Park Fairy Ring collected at the outer edge in September, 1877, and in the samples collected within the ring, and on the outer side of it, in April, 1878. In these cases also the cylinder brought up relatively small weights of soil, and hence the samples consisted in a relatively large proportion of surface soil, and showed accordingly higher percentages of nitrogen and carbon.

The general bearing of the results is unmistakably shown in the next table (V), in which, assuming each ring to be made up of the three divisions of "within," "on," and "outside," the results for each such division of the five different series of samples are brought together, and the mean taken. Thus, we have the mean of all the determinations on the samples taken within the ring, the mean of all those taken on the ring, and of all those taken outside it. At the foot of the table there is given the mean amount of nitrogen and carbon in the soils within, and on the ring, compared with that outside it taken as 100. There is also given the mean proportion of carbon to 1 of nitrogen in the soils taken at the different positions.

TABLE V.—*Mean Percentages of Nitrogen and Carbon in the Fine Dry Fairy Ring Soils.*

Description of ring.	Nitrogen per cent.			Carbon per cent.		
	Within the ring.	On the ring.	Outside the ring.	Within the ring.	On the ring.	Outside the ring.
Grove Paddock (May, 1874) ..	0·262	0·274	0·287	3·06	2·72	3·34
Broadbalk (June, 1877)	0·271	0·300	0·315	2·38	3·36	3·29
" (September, 1877) ..	0·226	0·244	0·274	2·48	2·60	3·12
Park (September, 1877)	0·222	0·253	0·259	2·88	3·21	3·31
" (April, 1878).....	0·253	0·257	0·269	3·12	3·04	3·44
Mean	0·247	0·266	0·281	2·78	2·99	3·30
N and C "outside" = 100	87·9	94·7	100	84·2	90·6	100
Carbon to 1 nitrogen.....	—	—	—	11·3	11·2	11·7

The results brought together in this way clearly bring to view the fact that in each of the five series of experiments the percentage of

nitrogen was the highest in the soil outside the ring, and the lowest in that within the ring. It was also in each case in intermediate amount in the soil on the ring. For the reasons already explained, the carbon results are not so trustworthy as those of the nitrogen. Still, the percentage of carbon is likewise in every case very much higher outside than within the ring; and it is, on the average, in intermediate amount on the ring. The general indications of the mean results may thus be safely relied upon. From these the conclusion already drawn from a study of the details becomes the more obvious, namely, that the growth of the fungus and the subsequent increased growth and removal of the associated herbage is accompanied by a considerable reduction in the amount of the organic nitrogen and carbon in the soil. Since prior to the growth of the fungus, that of the surrounding herbage was extremely restricted, and it became luxuriant only after the growth of the fungus, it cannot be doubted that it is primarily to its action that the reduction of the nitrogen and carbon in the soil is to be attributed. In other words, the fungi have taken up from the soil organic nitrogen and carbon that were not available to the previously established vegetation.

From the figures in the last line but one in the table, it is seen that reckoning the amount of nitrogen and carbon respectively outside the ring as 100, that of the carbon has been reduced in a greater proportion than that of the nitrogen, both on and within the ring. Accordingly the last line in the table shows that there was a higher proportion of carbon to nitrogen in the soil outside the ring than in that either on or within the ring. Calculation also shows that the proportion of carbon to that of the nitrogen lost by the soil is greater up to the stage of the active growth of the ring than afterwards, that is, the proportional loss of carbon is the greater under the more immediate influence of the growth of the fungus, and that of the nitrogen is the greater subsequently. Further, the relation of carbon to nitrogen is very much higher in the soil than it would be in the dry matter of the fungus. The action of the mycelium is therefore not only to reduce the carbon in a greater proportion than the nitrogen of the soil, but to do so in a much greater degree in proportion to the amount assimilated, a portion of the carbon being doubtless exhaled as carbonic acid. It is true that the proportion of carbon to nitrogen is much higher in the grasses which succeed the fungi than in the soil; but it is known that green-leaved plants generally, and grasses especially, derive most, if not all, of their carbon from the atmosphere.

Although the experiments do not supply data for exact calculation on the point, it may be stated, in general terms, that the mean results would represent a loss by the surface soil of several hundred pounds of nitrogen, and of several thousand pounds of carbon, per acre, by the

action of the fungus, and the subsequent luxuriant growth and removal of the grasses.

It was certainly to be expected that nitrates would be formed in considerable quantity on the decay of the fungus (whether in the stage of mycelium or of more advanced development), and possibly also on that of residual products of the action of the mycelium on the nitrogenous organic matter of the soil. It is quite in accordance with the supposition that nitrates are formed, that the band of grass following the track of the fungus should have the dark green colour which characterises it. It is, however, difficult to trace the formation of nitrates in meadow land, or at any rate to determine the quantity in which they are produced, as, owing to the amount and activity of the vegetation, they are for the most part taken up as soon as they are formed. Nevertheless, determinations of nitrates were attempted in the cases of the Broadbalk Field and of the Park Fairy Ring soils. The Crum-Frankland method was the one then in use, and was the one adopted. The soil extracts were purified by alcohol, but the chlorides were removed by silver. Under these circumstances the attack on the mercury was very feeble, and the nitrates present were undoubtedly under-estimated. The Broadbalk soils of the second collection have since been analysed by Schlösing's method, which is more accurate in the case of such extracts. The results of the determinations are given in Table VI below.

TABLE VI.—*Nitrogen as Nitrates per Million of Dry Fine Soil.*

	Crum-Frank- land method.	Schlösing method.
<i>Broadbalk Fairy Ring Soils, collected June 18, 1877.</i>		
Within the ring	0·23	—
On the ring	0·92	—
Just outside the ring	0·43	—
Outside the ring	0·09	—
<i>Broadbalk Fairy Ring Soils, collected September 15, 1877.</i>		
Within the ring	1·31	1·03
On the ring	8·07	11·46
Outside the ring	1·10	2·44

	Crum-Frank- land method.	Schlösing method.
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The Park Fairy Ring Soils, collected September 19, 1877.

Within the ring	trace	—
On the ring (centre)	0·46	—
On the ring (outer edge)	1·21	—
Just outside the ring	trace	—

The Park Fairy Ring Soils, collected April 25, 1878.

Within the ring	0·17	—
On the ring (inner side).....	1·21	—
On the ring (outer side).....	none	—
Outside the ring	0·18	—

It will be seen that in the case of the second series of samples from the Broadbalk Field Ring, there was a very considerable amount of nitric acid in the soil of the ring-band. In all other cases the quantity, if any, was very small. It was, however, always more abundant in the soil of the ring-band than either within or without the circle.

In making the extracts of the surface soils for the determination of nitrates, it was observed that when mycelium was present, the watery extract was dark-coloured, and gave a bulky organic residue on evaporation. It is to be supposed, therefore, that some of the products of the decay of the mycelium, or of the action of the mycelium on the soil, will pass by drainage into the subsoil.

Some of the subsoils were examined for nitric acid, but scarcely more than a trace was found, excepting in the subsoil collected under the ring-band at the second sampling of the Broadbalk Field Ring soils, where the table shows the highest amount in the surface soils. Even here, however, the nitrogen as nitrates in the subsoil amounted to only 0·82 per million of the dry soil.

On a review of the whole of the results of our examinations of the soils of fairy rings, we think there can be no doubt that the source of the nitrogen of the fairy ring fungi is the organic nitrogen of the soil itself, which it assimilates, presumably, though not certainly, as organic nitrogen, and eventually deposits as manure which becomes available to the associated herbage. Further, the whole of the phenomena of the fairy rings, so far as the nitrogen is concerned, are thus explained without supposing any intervention of atmospheric nitrogen.

Evidence is still wanting to prove whether at all, or in what degree,

some green-leaved plants have a power of assimilating the organic nitrogen of the soil, such as is possessed by the fungi. That Leguminosæ, for example, will take up more nitrogen from an arable soil than Gramineæ would from the same soil is certain. In some cases part, if not the whole, of the increased assimilation of nitrogen by the Leguminosæ is doubtless due to the arrest of nitrates that would have been lost by drainage in the case of the growth of Gramineæ. In others, the evidence at command does not justify the conclusion that the whole of the increased amount can be so accounted for. Again, under the influence of potassium salts applied as manure, leguminous plants will take up a considerably increased amount of nitrogen, even from a poor arable soil; whilst under the same conditions a gramineous crop would not do so. This action is very marked when potash salts are applied to grass land. In this case, however, the percentage of nitrogen in the much richer surface soil is reduced in a degree easily determinable by the soda-lime method. The question arises, therefore, how far the increased amount of nitrogen taken up under these circumstances, is due to a liberation of soil-nitrogen independently of any direct action of the plant itself; or whether, under the influence of the potash supply, the plant acquires a character, or increased activity, of underground growth, by virtue of which it is enabled to take up the organic nitrogen of the soil in a manner, or in a degree, of which it is not otherwise capable? Some Leguminosæ, however, which have very deeply distributed roots, have the power of assimilating very large amounts of nitrogen over a given area, when growing on arable soil with the surface impoverished, and the subsoil naturally poor, so far as nitrogen is concerned.