Note on the Occurrence of "Fairy-Rings."

By J. H. GILBERT, Ph.D., F.R.S., F.C.S.

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IT is known that "Fairy-Rings" occur chiefly, though not exclusively, on poor pastures, and that they are discouraged by high (especially high nitrogenous) manuring. In the experiments on permanent meadow-land, conducted in Mr. Lawes's Park at Rothamsted, there are twenty different plots, representing nearly as many different conditions of manuring, the same condition having been continued on the same plot in most cases for twenty years in succession. Some of these plots yield an average of little more than 1 ton of hay per acre, and others more than 3 tons. On some "fairy-rings" occur, whilst on others they do not. The flora generally, so to speak, has, indeed, changed under the influence of the different manures in a very striking degree. Thus, speaking roughly, there are certain plots on which there develop annually from 40 to 50 species or more, whilst in others even less than 20 are in some seasons found. These differences, it should be remarked, are the result of the different conditions as to manuring, the whole area, so far as could be judged, having been pretty uniform in the character of the herbage at the commencement of the experiments.

It will be of interest, and be found not irrelevant to the special subject of this communication, to summarize as briefly as possible a few of the most characteristic changes which have taken place in the botanical character of the vegetation under the influence of certain characteristic conditions as to manuring. On three occasions, at intervals of five years (namely, in 1862, 1867, and 1872), a sample of the produce from each plot has been carefully taken and submitted to careful botanical analysis. Taking the average of the three separations, the following are some of the results:—

Continuously without manure (plots 3 and 12), the number of species found in the produce has averaged 48, of which 17 are grasses, 4 belong to the order of Leguminosæ, and 27 to other orders. The percentage by weight of grasses is about 62, that of the leguminous herbage 8, and that of the remaining species, which it will be convenient to term *miscellaneous* herbage, 30.

With a purely mineral manure, containing superphosphate of

lime and sulphates of potass, soda, and magnesia, but no nitrogen or organic matter (plot 7), the average number of species found has been 42, of which, as without manure, 17 are grasses, 4 Leguminosæ, and the remainder "miscellaneous." But the produce has contained, on the average, only 55 instead of 62 per cent. of its weight of grasses, nearly 26 instead of only 8 per cent. (as without manure) of Leguminosæ, and only 19 instead of 30 per cent. of "miscellaneous" herbage.

With the same mineral manure as on the last plot (7), but with the addition of a large quantity of ammonia-salts, in plot 11, the average number of species found has been reduced to 21, of which 13 are grasses, 1 only belongs to the order of Leguminosæ, and 7 to other orders. But instead of 62 per cent. by weight of graminaceous herbage, as without manure, or 55 per cent., as with the mineral manure alone, we have now, with this mixture of the same mineral manure and a great excess of ammonia-salts, 92·5 per cent. by weight of grasses, only 0·01 per cent. of leguminous herbage, instead of 8 per cent. as without manure, and 26 per cent. with the purely mineral manure; and we have less than $7\frac{1}{2}$ per cent. of species from other orders, instead of about 30 per cent. as without manure, or 19 as with the purely mineral manure.

It will be readily understood that, with the great variety of manurial conditions offered by the twenty different experimental plots, there is very great variety in the development and relative predominance of the representatives of different orders and genera intermediate between the marked extremes above referred to. With reference to the extreme cases cited, the prominent point to observe is, that the grasses dominate to an extraordinary degree where large quantities of ammonia as well as mineral manure were employed, whilst, under these conditions, the leguminous herbage was all but annihilated, and the "miscellaneous" species were very much reduced both in number and in weight per cent. in the produce. On the other hand, the percentage proportion and the actual quantity of the leguminous herbage was enormously increased by a mineral manure containing potass but no ammonia, or nitrogen in any other form, or organic matter of any kind.

Here is obviously a remarkable instance of domination under well-defined artificially induced conditions. But the facts are the more remarkable since it is the Graminaceous herbage (which

under equal conditions of ripeness contains a comparatively low percentage of nitrogen) that is so strikingly developed under the influence of nitrogenous manures; whilst the Leguminous herbage, which is characterized by a very high percentage of nitrogen, is specially developed by mineral manure containing potass; and when to this nitrogenous manures (especially ammoniacal) are added, the plants of the Leguminous order are almost abolished.

These striking results, brought out in experiments on the mixed herbage of grass-land, are moreover perfectly consistent with those observed in the growth of individual Graminaceous and Leguminous crops in rotation on arable land. Thus, a crop of wheat, barley, or oats is, other things being equal, very much increased by nitrogenous manures. A crop of clover or beans, on the other hand, although it may yield three, four, or five times as much nitrogen over a given area, as a crop of wheat, barley, or oats growing on the same description of land, is not characteristically benefited by direct nitrogenous manures. But these Leguminous plants will develop and assimilate an enormous amount of nitrogen under conditions in which the Graminaceæ would languish, and they at the same time leave the land in improved condition for the growth of the Graminaceæ. It must be admitted that the source of the much larger quantity of nitrogen assimilated over a given area by plants of the Leguminous than of the Graminaceous family, and of the residue of it left by them in the upper layers of the soil in a condition available for the Graminaceæ, is not yet conclusively explained.

Reflecting upon these facts, Mr. Lawes and myself have often felt that if we could determine the source of the nitrogen of the fungi growing in "fairy-rings," some light might perhaps be thrown on the question of the source of the nitrogen of the Leguminosæ which we cultivate separately in rotation, or which grow in association in the mixed herbage of grass-land.

It will be readily understood that the nearly twenty conditions as to manuring, and the as many different conditions as to flora, which the experimental plots in the Park at Rothamsted offer, afford an extremely favourable opportunity for observing the conditions, both as to manure and association, under which fungi, and especially those occurring in the so-called "*fairy-rings*," most readily develop. Accordingly for some time past Mr. Lawes has observed their occurrence and development; and it is the

results of his observations on these points that I am enabled to communicate.

Before stating under which of the conditions of manuring "fairy-rings" have most developed, it is of interest to observe that, according to published analyses of various fungi, generally from one fourth to one third of their dry substance consists of nitrogenous matters. The dry substance further generally contains from 8 to 10 per cent. of mineral matter or ash, of which about 80 per cent. is phosphate of potassium. In fact, fungi would appear to be among the most highly nitrogenous of plants, and to be also very rich in potass. Yet the fungi have developed in "fairy-rings" only on the plots poorest in nitrogen and potass in such conditions as to be available to most other plants.

To go a little further into detail:—

In November 1874 six species of fungi were observed on the unmanured plot (3), where also they were more abundant than on any other plot. They were named by the Rev. M. J. Berkeley as follows—*Boletus erythropus*, *Hygrophorus pratensis*, *H. coccineus*, *H. virgineus*, *Agaricus geotrupus*, *A. æruginosus*.

On the plot with superphosphate of lime alone (4 . 1) there were two species, namely *Hygrophorus coccineus* and *Clavaria vermicularis*.

On plot 8, with superphosphate of lime and sulphates of soda and magnesia, but without potass for fourteen years, two species, *Hygrophorus virgineus* and *Agaricus nudus*.

On plot 17, with nitrate of soda alone, small patches of *Hygrophorus virgineus* and of *Agaricus furfuraceus* were found. On plot 16, with nitrate of soda and sulphates of potass, soda, and magnesia, a few of *Hygrophorus virgineus*. And on one or two other plots there were individual specimens of *Agaricus arvensis* of very large size.

"Fairy-rings" occurred almost exclusively on plot 4 . 1 (with superphosphate of lime alone), and on plot 8 (with superphosphate of lime, and sulphates of soda and magnesia, but no potass).

In May 1875 only one species, namely *Marasmius oreadum*, was observed.

On the 19th there were comparatively few specimens to be found. On the 31st they occurred in small numbers on plot 1 (with farm-yard manure and ammonia salts 1856–1863, but since ammonia salts only), on plot 2 (with farm-yard manure alone 1856–

1863, but since unmanured), on plot 3 (unmanured for more than twenty years), and on plot 7 (with superphosphate of lime and sulphates of potass, soda, and magnesia for twenty years). On plots 4.1 and 8, on the other hand, they could be counted by hundreds; and on these two plots only were they found in "fairy-rings."

On plot 4.1 (with superphosphate of lime alone) there were six more or less complete "fairy-rings," on some of which hundreds of the fungi were growing in thick patches, generally surrounded by the very luxuriant grass of the ring.

On plot 8 (with superphosphate of lime and sulphates of soda and magnesia but no potass for fourteen years) there were three large "fairy-rings" with the fungi growing very thickly on them, the grass of the rings being also very luxuriant. There were, besides these rings, a number of patches down one side of the plot showing many of the fungi and very luxuriant grass; and there was one large patch of very luxuriant grass showing no fungi now, nor was mycelium found in the soil; but in the autumn this patch gave a crop of *Agaricus nudus*. On this plot especially the increased growth of grass on the rings and patches where fungi have occurred is so considerable that it must appreciably affect the amount of produce on the plot; and the grasses most favoured seem to be *Poa trivialis* and *Holcus lanatus*.

Thus, then, the highly nitrogenous fungi flourished strikingly, and appeared in "fairy-rings," on two plots only, on neither of which is either nitrogen or potass applied as manure—conditions under which the development of the Graminaceæ is extremely restricted, and their limited growth is due to a deficient available supply of nitrogen, or of potass, or of both, and where the competition of the Leguminosæ is also weak, in the absence of a more liberal supply of potass.

The questions obviously arise whether the greater prevalence of fungi under such conditions be due to the manurial conditions themselves being directly favourable for their growth, or whether other plants, and especially the grasses, growing so sluggishly under such conditions, the plants of the lower orders are the better able to overcome the competition and to assert themselves. On this point the further questions arise whether the fungi prevail simply in virtue of the absence of adverse and vigorous competition, or whether 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; or, lastly, have these plants the power of assimilating nitrogen in some form from the atmosphere, or in some form or condition of distribution within the soil not available (at least when in competition) to the plants growing in association with them?

It is with the hope of arriving at some answer to these questions, either from the existing knowledge or the future observation of botanists and vegetable-physiologists, that we have felt it desirable to comply with the request made to us, to bring our own observations, made from a special point of view, before the Fellows of the Linnean Society. In aid of this object it may be well to state some other facts which we have noticed in connexion with the formation and extension of "fairy-rings."

It is probable that the fungi growing on meadow-land owe their occurrence in the first instance to the accidental droppings of animals or birds. Individual specimens appear, and sometimes grow to a large size, even on some of the highly manured plots; but patches, or "rings," are chiefly found on the poorly manured or exhausted plots—that is to say, where there is a marked absence of luxuriance in the vegetation generally. So far as may be judged from observation hitherto, patches may form and die out without development and extension into "rings." The formation of an annually increasing "ring" seems to require special conditions, both as to soil and association. In the case of mere patches, some examinations of the soil in spring and autumn have not shown a marked development of mycelium where it would be expected if there were to be extension, though it would appear that, if the conditions be specially favourable, they may enlarge and endure for some time. In the case of extending "rings," on the other hand, the soil under the outer portion of the circle generally shows, to a depth of a foot or more, according the character of the soil, an enormous development of mycelium for some time prior to the appearance of the above-ground growth.

It is to be particularly observed that this development of mycelium is always under the *outer* portion of the "ring," and is not found within it. When a ring is formed, what happens seems to be the following:—From some extraneous cause, such as above referred to, a patch of fungi is established. The plants falling and dying supply a rich nitrogenous (as well as mineral) manuring to the adjacent herbage. A patch of dark green luxuriant grass, generally several inches higher than the surrounding herbage,

succeeds. This being cut or eaten off, the soil may sooner or later become even more exhausted than before; and it is accordingly frequently observed that the grass within is less luxuriant than that outside the ring. Initiative experiments, upon which, however, we would not place implicit reliance, have, indeed, shown a lower percentage of nitrogen in the surface soil within the circle than at an equal depth either under or without the circle. Leguminous plants are not excluded from the area within the ring; but whilst *Lathyrus pratensis* and *Trifolium pratense*, plants which on the land in question have shown themselves very dependent on artificial supplies of potass, seem to be discouraged, *Lotus corniculatus* and *Trifolium repens*, species which maintain their position under marked conditions of exhaustion of soil, are fairly abundant. At any rate, it would appear that, in the case of "rings," the soil underneath the fungus-growth has become unfitted to support another crop, or successive crops, of fungi. Accordingly, supposing the soil of the plot to be favourable, the ring develops always outwards—that is, on what is to the fungi virgin soil; and hence the annual enlargement.

It will be seen that in these facts we have an interesting illustration of what may be called natural rotation. The original fungi probably receive their nutriment from extraneous sources; but once established, they must, for the extension into "rings," depend upon other supplies, which, if due to the soil itself, are obviously unfavourable, either in condition or in distribution, to the surrounding vegetation, and especially to the grasses, which do not flourish until the matter taken up by the fungi becomes available to them as manure, when at once they show very great luxuriance. Or is it, as already suggested, that the mycelium develops, so far as its nitrogen is concerned, not at the expense of that which may be said to have become a constituent of the soil itself, but of that accumulated in the vegetable débris from former growth within the soil, or even parasitically—that is, at the expense of the nitrogenous matters of the roots of not dead but very sluggish vegetation?

These points are obviously of very considerable interest from both a chemical and a physiological point of view; and it is much to be hoped that botanists and vegetable physiologists who may have special knowledge on the subject will bring it to bear on the questions which seem to be at issue—or that, in so far as such knowledge is not yet available, some may be induced to take up

the investigation with a view to the elucidation of that which, to us at least, seems to require explanation *.

Extract from a Letter from I. B. Balfour, Esq., Botanist to the Expedition to Rodriguez to observe the Transit of Venus; addressed to, and communicated by, Dr. Hooker, F.L.S.

[Read May 7, 1874.]

I have done a good deal of work since I came here, and have explored the major part of the island. It is only $10\frac{1}{4}$ miles long by 4 miles broad, much smaller than previously supposed; but the huge boulders and stones which cover the ground over the whole island render walking both difficult and dangerous.

The flora is by no means extensive; and it is curious to note how very restricted in area are the habitats of many of the plants. In several cases the plant from which I have gathered my specimen was the only individual of the species which I have seen in the island.

I do not know enough about the Mauritian flora to make any comparison; but several of the ferns which I have seen seem to be identical with Mauritian ones.

The Vacoas (*Pandani*) are extremely puzzling. The inhabitants say that there are four kinds, calling them *Vacoa sac*, *V. poteau*, *V. chevron*, and *V. parasol*; others make five, adding *V. mâle*; whilst others, again, substitute a *V. calé* for the *V. sac* and *V. parasol*. For my part, I think at present the *V. poteau* and *V. chevron* are the only two species, the former growing on the shore and also on the hills, the latter only on the hills. The *V. sac* is just the young plant of the *V. poteau* with large leaves; the *V. mâle* is merely the male tree of either of the species; and the *V. parasol* seems to be nothing but the *V. poteau* growing where it has free scope to develop its branches regularly and form a dome, the *V. calé* being a dwarfed stunted form of *V. poteau* when exposed to wind &c. The fruits of all those trees which I would group under *V. poteau* vary very greatly, both in size, colour, and form; but the habits of the trees are quite the same. These are at present my ideas regarding them; but I intend devoting a great deal more time to them.

* Owing to pressure of occupation at the time, I was not able to refer to the opinions of others before writing the foregoing notes, but have since done so, and would call attention to the observations of Berkeley, Way, Buckman, Lees, and others,—J. H. G.