The Rothamsted Agricultural Experiments
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fertilisation takes place. This in fact we must conclude from observational evidence takes place in both the primrose and in the cowslip.

THE ROTHAMSTED AGRICULTURAL EXPERIMENTS.

THOUGH Rothamsted is a household word to agriculturalists all the world over, and the value of its long series of experiments are doubtless fully appreciated, it may be questioned if botanists in general are fully aware of the importance and extent of the purely botanical aspects of the work that is being carried on at the station for scientific experiments in agriculture founded more than sixty years ago by the late Sir (then Mr.) John Bennet Lawes on his estate close to the little town of Harpenden in Hertfordshire.

The history of the station is briefly as follows. In the year 1843 Mr. Lawes, who had succeeded to the Rothamsted property in 1834 and being of a chemical turn of mind had already experimented with various chemical manures and obtained excellent results with "superphosphates" for turnips, results which had led him to patent their manufacture in 1842, started the systematic series of experiments which have been continued down to the present day. He seems to have been partly spurred thereto by the lectures of Liebig delivered at the Royal Institution. Liebig taught that plants derived not only their carbon but also their nitrogen from the atmosphere, and on this he founded his doctrine of *mineral manuring*, or the putting back into the soil of the ash constituents which the plant has taken from it. Lawes found that this theory did not square with his practical experience, and selecting certain fields from his estate, and devoting a barn to the purposes of an agricultural laboratory, began the great series of experiments which have been carried on continuously from 1843 till the present day.

In that year also Lawes obtained the services of Dr. (afterwards Sir) Henry Gilbert to take charge of the laboratory, and Gilbert remained as Chief Chemist and Director till his death in 1901. So long ago as 1854, a number of leading agriculturalists, desiring to shew their appreciation of the work, presented Lawes with the present laboratory, and the work of several chemical and general assistants was from an early date involved in carrying out the routine work of analysing soil samples and ash constituents. In 1889 Sir John Lawes with far-sighted munificence set aside a trust fund of £100,000 as well as the 50 acres or so of experimental ground, and the laboratory and sample room, to be bequeathed to a trust for the continuance of the work after his death, which took place in 1900. This is not the place to give even the briefest summary of the splendid results of Lawes' and Gilbert's work. Our present object is to direct attention to some of the more striking botanical lessons to be learned from a visit to Rothamsted at the present day.

On the death of Sir Henry Gilbert at the end of 1901, Mr. A. D. Hall, at that time Principal of the South Eastern Agricultural College at Wye, was appointed Director of the Station by the Lawes Trustees, and he is not only carrying on the unbroken series of manuring experiments inaugurated by Lawes and Gilbert, but has also started important new lines of research.

Some of the lessons of the Rothamsted experiments were developed by Mr. Hall in the lectures he gave last autumn for the University of London at the Chelsea Physic Garden on "The Constitution of the Plant in Relation to Soil," and many of those who attended these lectures have recently had an opportunity of visiting Rothamsted and seeing for themselves, under Mr. Hall's guidance, some of the effects of the differences of nutrition to which various agricultural crops have been subjected for so many years.

Effect of Manuring on Meadow-Land.

Perhaps the most striking and instructive experiments from a general botanical point of view are those which shew the effects of long continued differential manuring of meadow land. In 1856 an area of about seven acres of land in Rothamsted Park, which had been permanent grass for at least 200 years, was divided into a number of plots for differential treatment, and since that time each plot has been continuously treated with a definite quantity of a particular manure. Twice every year the grass is cut and an estimate is made, not only of the total weight of hay from each plot, in cwts. per acre, but also of the botanical composition of the hay, *i.e.* of the percentages of the different species of plants in the total dry weight of the crop.

The cumulative effect of the differential manuring, not only on the quantities of hay produced but especially on the species of plants growing on the different plots, is most stirikngly evident to an observer visiting the experimental area in the middle of June, just before the cutting of the grass. One plot will be bright with buttercups and sorrel, while the adjoining one shews not a single flower, but is entirely composed of tall dark-green meadow-grasses, and a third is covered with the graceful white umbels of Anthriscus.

This striking effect, it must be remembered, has been brought about in what was originally perfectly uniform meadow-land, entirely by differences of manuring, which have so changed the conditions of the struggle for existence in each individual plot, as to bring about the success of a different combination of species in each case, and thus to produce a number of distinct floras living side by side, bounded by mathematically straight lines and apparently never trespassing across them.

Of course the component species of these floras are all inhabitants of meadowland of one kind or another, and several are common to the majority of the plots, but it is a striking fact that some of the plants which occur on plots subjected to the most extreme conditions, particularly on the starved plots, are not only not found on the ordinary grass land adjacent, but are nowhere common in the surrounding country side. Thus for instance *Poterium Sanguisorba*, the Salad Burnet, characteristic of dry chalk downs is found only and is very common on the two most starved plots, *i.e.* the plot which has been unmanured since 1856, and the plot which has been exhausted by treatment with superphosphate of lime alone since 1859; while *Briza media*, the Quaking Grass, universally taken as a sign of poor land, occurs in any quantity only on these two and on the plot which has no potash. Neither of these plants are conspicuous, at any rate, in the countryside. It would be an enquiry of some interest to determine what are actually the nearest habitats of these species, from which presumably the colonisation of the two plots must have occurred.

The two most starved plots bear a varied herbage (47 species) consisting mainly of weede (*i.e.* plants which are of little use as constituents of hay, and which stock generally refuse) and are very poor in grasses, particularly in the valuable ones.

Manuring with combined nitrogen, on the other hand, either in the form of ammonium salts or nitrate of soda, though in the absence of the other mineral manures it gives but a poor and weedy crop, encourages the grasses at the expense of the leguminous plants.

A complete manure, consisting of the necessary mineral constituents together with combined nitrogen, enables the grasses largely to suppress the competition of the "weeds" and completely to exclude the leguminous plants. With increase in the amount of combined nitrogen the "weeds" become still fewer, and the weight of hay rapidly increases, though the number of *species* of grass becomes very restricted. Thus in one very heavily "over-manured" plot there are only ten species of plants altogether, and 99·8% of the dry weight of the crop is composed of grasses, almost entirely of three species. This crop usually goes flat before cutting, and is particuarly liable to the attacks of fungi.

Treatment with a mixed mineral manure, including the indispensable potash, but excluding nitrogen, has caused a great increase of leguminous plants (mainly clover), which sometimes form 50% of the dry weight of the crop. This is of course because these plants, being independent of combined nitrogen, when they are supplied with the indispensable potassium, gain a great advantage over the grasses, which do require combined nitrogen. There are, however, actually more grasses in the hay of this plot than in that of an unmanured plot, because these plants live at the expense of the combined nitrogen in the humus formed by the leguminous plants.

The specialisation of the vegetation, according to whether the food-constituents in the manures are retained at the surface or penetrate more deeply into the soil, is also very clearly brought out. Thus the plots manured with ammonium salts bear a shallow-rooted vegetation with such grasses as *Festuca ovina* and *Anthoxanthum odoratum*, while those manured with sodium nitrate give deep-rooted crops with *Bromus mollis* and *Avena elatior* dominant. The plot manured with a complete manure, the nitrogen as sodium nitrate, is also strikingly characterised by the abundance of *Anthriscus sylvestris*, which, as is well-known, ordinarily frequents hedge sides and the shade of trees, often in company with *Bromus*. Why the nitrate manuring should encourage it in the open is not at all obvious.

We have only alluded to a few of the more important conclusions that may be deduced from this extremely beautiful series of experiments. They suggest subjects for fresh enquiry on every hand. Perhaps the most important general lesson is the emphasis given to the keen competition of different species in the struggle for existence, and the enormous advantage given to certain species over others by comparatively slight alterations in the conditions of life. The working of some of these alterations we are able to trace, while others still remain a mystery; but there can be no doubt that long continued systematic experiment of this kind is the surest means of throwing light on the often perplexing combinations of species in natural floras.

WHEAT.

Broadbalk Field, about eleven acres in extent, has been continuously under wheat for sixty-one years, parallel strips having been treated with different manures.

Even the unmanured plot still continues to produce a crop every year, and its average crop for the last half century (thirteen bushels to the acre) is about the same as the world's average, though the English farmer expects a much heavier crop than this. The plot receiving a mixed mineral manure without nitrogen, produces very little more than the unmanured plot; with nitrogen the crop increases greatly, and a progressive increase of nitrogen leads to a corresponding increase in the crop. Thus we see, as we saw in the case of hay, that combined nitrogen is *the* great requirement of the grass-plant. One of the great objects of changing the crop on a piece of land is to get rid of the weeds especially associated with a given crop, which would otherwise increase to a harmful extent. This is seen on Broadbalk field, where the wheat had become so "foul" with *Alopecurus agrestis*, the Black Bent Grass, that the experiment is being tried of fallowing half of each plot in alternate years, in order to get rid of the pest.

One end of Broadbalk field was left entirely to itself many years ago. In comparatively few years the wheat entirely disappeared, its place being taken by a miscellaneous mixture of weeds, among which were a number of seedling bushes and trees. In another few years the bushes formed an impenetrable thicket, through which the young trees, largely oaks, were beginning to push their way. In another thirty years there would have been a young oak wood with rich undergrowth, but the bushes were in the way and have been recently stubbed up. The succession of events illustrates the constant tendency of good land to go back to the condition of woodland (no doubt its primitive state throughout the temperate regions) a tendency only arrested by the constant cutting of crops or by grazing.

Clover-Sickness.

A very interesting experiment with leguminous plants has been made in Hoos Field.

Various leguminous crops have been grown continuously since 1848 with various combinations of mineral manures, but after the first few years they became a complete failure, owing to an unknown cause which nearly always prevents the continuous growing of leguminous crops and is called by farmers "clover sickness." The bulk of this area was ploughed up in 1898 and sowed with wheat. Five crops of this were taken without manuring in succeeding years to test the amount of nitrogen accumulate d by the leguminous plants and left in the soil. Heavy crops of wheat were taken the first year, but in subsequent years they fell off greatly, in some cases to the "unmanured" level at once, in others more gradually. The residue of nitrogen left by lucerne is still palpable six years after the discontinuance of its growth. This year oats have been sown instead, and in the oats, leguminous plants again. This will shew if the ground has recovered from the "clover-sickness." Meanwhile the extreme ends of the original "clover-sick" strips are still under their impoverished leguminous crops, and wretched plants, for the most part, they are.

Many interesting lines of research that are being carried on at Rothamsted cannot be entered into here. No mention for instance has been made of the manuring experiments with root crops, nor of the investigations which Mr. Hall is pursuing with the object of trying to understand that still mysterious property, the "strength" of wheat, or rather of the dough made from it, a property which enables certain foreign wheats, such as American and Russian, to fetch substantially more in the market than the best English-grown crops. But enough has been written to give some idea of the extraordinary botanical interest attaching to the work which was begun by Lawes, and which his admirable generosity has made it possible to continue indefinitely. A. G. T.

AN EXHIBIT OF SPECIMENS OF SEED-BEARING PLANTS FROM THE PALÆOZOIC ROCKS.

THE readers of this Journal have been kept informed as to the recent additions to our knowledge of the early fern-like Gymnosperms.[1] On the occasion of the recent conversazione held by the University of London on the 27th of May, a considerable collection of specimens was brought together by the chief workers in this field, illustrating not merely the newer work, but as far as possible also the habit and appearance of the palæozoic plants known to bear seeds or seed-like structures.[2]

In view of the fact that a new group, the Pteridospermeae

1 New Phytologist, Vol. II., p. 73; Vol. III., pp. 32 and 102.

2 The following sent contributions :—Mr. E. A. Newell Arber, Miss M. Benson, Mr. R. Kidston, F.R.S., Professor F. W. Oliver and Dr. D. H. Scott, F.R.S.