

NOTES ON THE BOTANY OF THE EXPERIMENTAL GRASS-PLOTS IN ROTHAMSTED PARK, HERTS.

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Most English botanists are acquainted with the extensive series of experiments which Mr. Lawes, assisted by Dr. Gilbert, has been conducting on his estate at Rothamsted for upwards of thirty years. Independently of their value in practical agriculture, these experiments possess great interest for the student of botany, whether systematist or physiologist. Indeed, it would be difficult to overestimate their value. Besides these experiments in the open fields, it is only necessary to mention the results of the laboratory work, published under the titles, "On the Sources of the Nitrogen of Vegetation; with special reference to the question whether plants assimilate free or uncombined Nitrogen,"* and a "Report upon some Experiments undertaken at the suggestion of Professor Lindley to ascertain the comparative Evaporating Properties of evergreen and deciduous Trees,"† to show the importance of the labours so patiently and perseveringly continued at an immense outlay, and during a period when comparatively few scientific men, in this country at least, took any real interest in the issues. Even now it is doubtful whether Mr. Lawes receives that sympathetic support which is due to him and his coadjutors for their contributions to science. The greatest reward a man can enjoy, however, is the satisfaction he feels at having discovered a new fact; and a proof of Mr. Lawes's earnestness in his investigations is found in the provision he has made for the continuation of this experimental research after his death. Many of the field experiments were originally instituted to ascertain in what form certain essential elements in the food of plants could be most advantageously applied. That is to say, in such a form that plants could assimilate them, and at an outlay that would prove profitable to the farmer.

It is not the purpose of the present writer to enter into these questions in detail here, but rather to point out some of the features of one particular set of experiments which specially come within the domain of what may be termed the biological botanist.

For a number of years many of the experiments at Rothamsted, notably those on the herbage of permanent meadow land, which alone will be considered here, have been carried on for purely scientific purposes. As in all investigations, the results of which have not been reduced to plain facts, some little time and patience are necessary to obtain a grasp of the subject, especially as the questions at issue are numerous. There are some twenty variations of what may be termed the same experiment; but in order to appreciate their full significance it is only necessary to bear in mind that the investigations, so far as the nutrition of the plant are concerned, are limited to the presentation,

* Philosophical Transactions, part ii., 1861.

† Journal of the Horticultural Society of London, vol. vi, parts 3 and 4 (1861).

in diverse combinations, of the elements nitrogen, phosphorus, potassium, sodium, &c., or those elements which are indispensably necessary in the life of the plant, and of which the soil is soonest exhausted. The elements, in short, which must be supplied by man to ground under constant cultivation, in contradistinction to such elements as carbon and the constituents of water, the supply of which is inexhaustible.

It is also important to remember that these elements, especially the metals, some of which are known to be intimately associated with the activity of certain vital functions, as iron in the production of chlorophyl, and potassium in the assimilating powers of the latter, form together only a very small proportion of the total weight of vegetable organisms. It has also been asserted by some physiologists that plants are unable to attain their proper development in a soil or atmosphere overcharged with certain elements. Be that as it may, a glance at the large wall-case exhibited by Mr. Lawes in the Loan Collection at South Kensington, or a visit to the experimental ground at Rothamsted, will at once impress the mind with the strikingly different results obtained in the character and quantity of the herbage under the influence of diverse manures. Having been employed by Mr. Lawes for some time on these experiments, the results of which have not yet been sufficiently elaborated for publication, I thought botanists would welcome some notes on the flora of the area under experiment, as they might render the forthcoming exhaustive memoir more interesting and intelligible, and at the same time draw more general attention to the experiments themselves.

Although the results of my work and that of others, which, of course, belong to Mr. Lawes, have only partially been made public, that gentleman kindly assented to my request to be permitted to use some of the knowledge obtained while in his service. Naturally I shall avoid giving information here that would detract from the interest of the approaching report. My object is rather to create a desire in some botanists to make themselves familiar with the nature and significance of these experiments, because I believe that they furnish the material for solving various problems and interesting questions in plant life—problems requiring much time and some scientific training to work them out. In fact, my experience at Rothamsted was that every fresh step suggested some new line of inquiry.

Within the limits of this article I can only run over the surface of the prominent features of the composition of the vegetation of the experimental grounds. To attempt to give in a few words an idea of the whole subject would only be confusing.

From time to time Messrs. Lawes and Gilbert have published various reports on these experiments in the "Journal of the Agricultural Society," the principal one relating to analyses of the proportions, or percentages, of the various species constituting the herbage of each plot. To this paper the reader is referred for much information relative to the manuring and the general effects at that date. The meadowland under experiment is a portion of Rothamsted Park, about seven acres in extent, and nearly level. The soil is a somewhat clayey loam, and appears to be tolerably uniform throughout, with a clayey subsoil of several feet in depth, immediately overlying the chalk. Respecting its condition when the experiments were commenced, it is stated in

the annual memoranda sheet issued by Mr. Lawes, "The land has probably been laid down with grass some centuries. No fresh seed has been artificially sown within the last forty years certainly, nor is there record of any having been sown since the grass was first laid down. The experiments commenced in 1856, at which time the character of the herbage appeared uniform over all the plots." The ground was not thoroughly botanised at the outset, and therefore it is not on record what species originally grew on each plot; but it is not difficult to prove, as stated above, that the herbage was pretty uniform over all the plots.

In 1862 the first attempt at a separation of the species of average samples of the hay of each plot was undertaken, and this was on the whole successful; but from some difficulties which will be explained further on, some of the details are not quite accurate. However, the errors are so trifling as to barely affect the main issues. A report of the results appeared in the "Journal of the Royal Agricultural Society," vol. xxiv., part 1. In 1867 another set of samples was taken and analysed, again in 1872, and I believe it is the intention of Mr. Lawes to have the fourth set taken next season. On each occasion the ground has been thoroughly botanised, and notes made on the character of growth exhibited by each species on the different plots where it occurred. In 1872 I spent at least six weeks on these plots, and carefully examined every inch of the ground of each plot, and enumerated the plants constituting the herbage.

The exact composition of the herbage of the unmanured plots will doubtless be of great interest to botanists, and serve as a standard for comparison with floras of similar areas in other parts of the country. In the first place, I will give a complete list of all the plants hitherto observed growing on the whole area of about seven acres.

1. *Ranunculaceæ*.

1. *Ranunculus acris*, 2. *R. repens*, 3. *R. bulbosus*, 4. *R. auricomus*,
5. *R. Ficaria*.

2. *Cruciferae*.

6. *Cardamine pratensis*.

3. *Caryophylleæ*.

7. *Stellaris graminea*, 8. *Cerastium triviale*.

4. *Hypericineæ*.

2. *Hypericum perforatum*.

5. *Leguminosæ*.

10. *Ononis arvensis*, 11. *Trifolium repens*, 12. *T. pratense*, 13. *T. procumbens*, 14. *Lotus corniculatus*, 15. *Lathyrus pratensis*, 16. *Vicia Cracca*, 17. *V. sepium*.

6. *Rosaceæ*.

18. *Potentilla reptans*, 19. *P. Fragariastrum*, 20. *Alchemilla vulgaris*, 21. *Agrimonia Eupatorium*, 22. *Poterium Sanguisorba*, 23. *Spiræa Ulmaria*.

7. *Umbelliferae*.

24. *Conopodium denudatum*, 25. *Pimpinella Saxifraga*, 26. *Heraclium Sphondylium*, 27. *Anthriscus sylvestris*.

8. *Rubiaceæ*.28. *Galium verum*, 29. *G. Aparine*.9. *Dipsacæ*.30. *Scabiosa arvensis*.10. *Compositæ*.31. *Centaurea nigra*, 32. *Carduus arvensis*, 33. *Bellis perennis*, 34. *Achillea Millefolium*, 35. *Chrysanthemum Leucanthemum*, 36. *Senecio erucæfolius*, 37. *Hypochaeris radicata*, 38. *Tragopogon pratensis*, 39. *Leontodon hispidus*, 40. *L. autumnalis*, 41. *Taraxacum officinale*, 42. *Hieracium Pilosella*, 43. *Sonchus oleraceus*.11. *Plantagineæ*.44. *Plantago lanceolata*, 45. *P. media*.12. *Scrophularinæ*.46. *Veronica Chamædrys*, 47. *V. serpyllifolia*.13. *Labiataæ*.48. *Thymus Serpyllum*, 49. *Prunella vulgaris*, 50. *Ajuga reptans*.14. *Primulaceæ*.51. *Primula veris*.15. *Polygonaceæ*.52. *Rumex Acetosa*, 53. *R. obtusifolius*, 54. *R. crispus*.16. *Orchidaceæ*.55. *Orchis Morio*.17. *Liliaceæ*.56. *Scilla nutans*, 57. *Fritillaria Melcagris*, 58. *Ornithogalum umbellatum*.18. *Juncaceæ*.59. *Luzula campestris*, vars. *campestris* and *congesta*.19. *Cyperaceæ*.60. *Carex præcox*.20. *Gramineæ*.61. *Anthoxanthum odoratum*, 62. *Alopecurus pratensis*, 63. *Phleum pratense*, 64. *Agrostis vulgaris*, 65. *Aira cæspitosa*, 66. *Holcus lanatus*, 67. *Avena elatior*, 68. *A. pubescens*, 69. *A. flavescens*, 70. *Poa pratensis*, 71. *P. trivialis*, 72. *Briza media*, 73. *Dactylis glomerata*, 74. *Cynosurus cristatus*, 75. *Festuca ovina* (varieties), 76. *F. pratensis*, 77. *Bromus mollis*, 78. *Lolium perenne*.21. *Filices*.79. *Ophioglossum vulgatum*.22. *Musci*.80. *Hypnum squarrosum*, 81. *H. rutabulum*, 82. *H. hians*.23. *Fungi*.*83. *Agaricus arvensis*, 84. *A. nudus*, 85. *A. æruginosus*, 86. *A. geotrupus*, 87. *A. furfuraceus*, 88. *Boletus erythropus*, 89. *Clavaria*

* This list of Fungi is extracted from Dr. Gilbert's paper on the "Fairy-Rings" of the plots in "The Journal of the Linnean Society," vol. xv. The species were determined by Mr. Berkeley.

vermicularis, 90. *Hygrophorus coccineus*, 91. *H. virgineus*, 92. *H. pratensis*, 93. *Marasmius oreades*.

The complete flora may thus be summarised :—

Total number of species	93	
„ „ „ genera	67	
„ „ „ orders	23	
„ „ „ Dicotyledons	54	} =93
„ „ „ Monocotyledons	24	
„ „ „ Acotyledons	15	

The foregoing list, it will be seen, includes several species not commonly met with on meadow land, the presence of which may be regarded as accidental. Such, for instance, as *Ranunculus auricomus*, *Vicia Cracca* and *sepium*, *Galium Aparine*, *Sonchus oleraceus*, *Fritillaria Meleagris*, and *Ornithogalum umbellatum*. These, and some twenty other species, are represented only by a few individuals, and, practically speaking, form no appreciable proportion of the crop. On the other hand, many common meadow plants will be missed, as *Lychnis Flos-cuculi* and other species, *Lotus major*, *Silvus pratensis*, and *Senecio Jacobæa*. The elevated situation and good drainage explain the almost total absence of *Cyperaceæ*, and other moisture-loving plants. It has already been mentioned that we have good evidence that the herbage was tolerably uniform all over the plots when the experiments were first started. This is afforded by the present composition of the herbage around the experimental grounds, and more particularly that of the two plots left unmanured from the beginning. These plots are each a quarter of an acre in extent, and, exclusive of the Fungi, about sixty of the remaining eighty-two species enumerated above occur on each plot, and fifty of these were represented in the sample separated into its constituent species in 1872. With the exception of about half-a-dozen rare species they are the same on both plots. Now, if we compare the flora of an unmanured plot with that of 11a, a contiguous plot, we find the number of species reduced to eighteen, or less than one-third, whereof sixteen were found in the sample. This plot, it should be mentioned, receives an annual dressing of 300 lbs. sulphate of potass, 100 lbs. sulphate of soda, 100 lbs. sulphate of magnesia, 3½ cwt. superphosphate of lime, and 800 lbs. of ammonia-salts per acre. The effect of this large quantity of manure is to stimulate some of the coarser-growing grasses and other plants to extraordinary growth, and crowd out or otherwise cause to disappear, about forty species, some of which on the unmanured plot hold an equally good or better footing in the struggle for existence. The species found in the sample taken from 11a in 1872 are:—*Anthoxanthum odoratum*, *Alopecurus pratensis*, *Agrostis vulgaris*, *Holcus lanatus*, *Avena elatior*, *A. flavescens*, *Poa pratensis*, *P. trivialis*, *Dactylis glomerata*, *Festuca ovina*, *Bromus mollis* (a fragment), *Trifolium repens* (a few leaves only), *Conopodium denudatum*, *Prunella vulgaris* (probably from quite near the margin of the plot, and not really belonging to it), *Rumex Acetosa*, and *Carex præcox* (a leaf or two). But a few figures will give a better idea of the composition of the herbage of this

plot, which yields an average spring crop of more than three tons of hay, than a mere list of the species. The figures indicate the percentage by weight of each species in the total weight of the spring crop. *Alopecurus pratensis*, 12·35; *Agrostis vulgaris*, 13·56; *Holcus lanatus*, 10·33; *Avena elatior* (*Arrhenatherum avenaceum*), 10·41; *Poa pratensis*, 10·40; and *Dactylis glomerata*, 39·28. Altogether, these six grasses formed 96·33 per cent. of the crop of 1872. In their tables Messrs. Lawes and Gilbert give the percentages of the graminaceous, the leguminous, and the herbage of other orders. Those of the plot named for 1872 are respectively 98·81, 0·01, and 1·15. It would occupy too much space here to enter into the many interesting details of these changes; but there is the question how far the various manures exercise an influence on the botanical characters of the plants that calls for a word, and this will be referred to again further on. The grasses that constitute so large a proportion of the herbage on plot 11a are also all found on the unmanured plot, but the relative proportions are quite different, and several species which do not occur on the former are generally distributed over the unmanured. Taking a few species in illustration of this fact, we have:—

	Unmanured.	Highly Manured (11a)
<i>Anthoxanthum odoratum</i>	5·20	0·78 per cent.
<i>Briza media</i>	6·40	absent.
<i>Festuca ovina</i>	21·67	0·38. „
<i>Avena pubescens</i>	3·55	absent.
<i>A. flavescens</i>	3·49	0·09. „
<i>Cynosurus cristatus</i>	1·11	absent.
<i>Avena elatior</i>	0·13	10·41. „
<i>Dactylis glomerata</i>	0·90	39·28. „
<i>Alopecurus pratensis</i>	0·52	12·35. „
<i>Poa pratensis</i>	0·09	10·40. „

The general composition of the unmanured herbage is:—Graminaceous, 68·66; leguminous, 8·98; other orders, 22·36 per cent.—a kind of herbage very much relished by cattle, but the average crop for eighteen years is only a little over a ton per acre. Between these two extremes, according to the manure applied, the development of different species is very diverse, and some of the facts are not easily explained. A few of the more remarkable cases may be quoted. The quantities of manure are always at the same rate per acre. With 550 lbs. nitrate of soda, 300 lbs. sulphate of potass, 100 lbs. each of the sulphates of soda and magnesia, and 3½ cwts. of superphosphate of lime, *Bromus mollis* and *Poa trivialis* are developed to an extraordinary degree. Sometimes the one preponderates and sometimes the other, the cause of which I have not worked out; but I imagine it is connected with the rainfall and other climatal conditions. In 1872 the *Bromus* formed 42·10 and the *Poa* 24·76 per cent. of the herbage, associated with 3·86 per cent. of *Anthriscus sylvestris* in a total of 5·77 per cent. of “other orders.” With 400 lbs. of ammonia-salts and 3½ cwts. of superphosphate of lime, there was 49·29 per cent. of *Festuca ovina*, and 20·59 of *Agrostis vulgaris*, with scarcely any

flowering-stems of any plant. On another plot, similarly manured to 11a, *Dactylis* formed nearly 55 per cent. of the total produce. A crop singularly rich in the leguminous element is the result of another combination of manures, and in an adjoining plot, to which no sulphate of potass is applied, the contrast is very marked. Thus leguminous plants formed about 40 per cent. of the herbage on the first, and only about 8 per cent. where there was no potass.

Sufficient illustration for the purpose in view has now been given of what Dr. Gilbert terms the "domination of one plant over another." A few remarks on some of the principal plants which do not belong to either the *Leguminosæ* or the *Gramineæ*, must terminate this part of the subject. *Ranunculus acris*, *R. bulbosus*, *Trifolium pratense*, *Lathyrus pratensis*, *Pimpinella Saxifraga*, *Centaurea nigra*, *Achillea Millefolium*, and *Luzula campestris* occur on all the plots except 11a and 11b, on which the quantity of ammonia-salts applied per acre is 800 lbs. annually; and these plants are all very conspicuous in their flowering season. *Achillea* rarely throws up any flowering-stems before the first crop is cut, and the leaves in the sample, which are comparatively very light, by no means represent the extent to which this plant has possession of the soil. But the leaves alone of this plant form about 10 per cent. of the herbage of one plot. *Conopodium denudatum*, *Heracleum Sphondylium*, and *Rumex Acetosa* occur on all the plots, but the second is in most instances represented by only one or two plants. The *Rumex* is very abundant all over, and constitutes on most plots a large proportion of the miscellaneous herbage, and in rare cases it has almost or quite reached 25 per cent. of the total weight of the sample. *Cardamine pratensis*, *Stellaria graminea*, *Chrysanthemum Leucanthemum*, *Senecio erucifolius*, *Hypochaeris radicata*, *Plantago media*, *Primula veris*, *Orchis Morio*, *Scilla nutans*, and several other species which are common in many meadows, are rare here. *Fritillaria* occurs sparingly on one plot, but it is rather plentiful in a not very distant part of the park; and *Ornithogalum umbellatum* is quite rare. *Plantago lanceolata* grows on all the plots except where ammonia-salts are applied, having disappeared from several of these plots since 1862 or 1867.

In conclusion, a few words respecting the analyses or separations of the samples of hay into their constituent species, a labour which at first appears to present insurmountable difficulties, and which no botanist can perform without special training, but with a little practice it is easily accomplished. It is, however, exceedingly trying work for the eyes. Sharp boys, from ten to twelve years of age, learn to distinguish most of the species, even very small fragments of the leaves of any of the grasses, in a fortnight or three weeks; and some of them after a month's teaching perform the operation as well as it is possible to do it. It would occupy much space to describe fully the mode of taking and separating the samples, but it will be understood that the greatest care is exercised throughout, and no time is spared in endeavouring to obtain a fairly representative sample of the herbage of each plot. The characters by which the various species are recognised in the condition of hay were only discovered by degrees, and therefore the first separations were not so well done as the later ones, and a larger proportion was left undetermined. But

in 1872 we had the experience gained in former years to aid us in starting, and the amount of undetermined was in the majority of cases less than one per cent. The only really indeterminable parts are the portions of grass culms that are quite destitute of leaves and flowers. Hence great care is necessary after the sample is dry not to break the stems to pieces. Generally speaking, the smallest scrap of a leaf may be identified, as well as the glumes and the grain of the grasses. Of seeds or fruits belonging to any of the other orders very few enter into the samples. The achenes of the *Ranunculi*, seeds of *Cerastium*, mericarps of *Conopodium* and *Anthriscus*, achenes of *Tragopogon*, *Taraxacum*, and *Rumex*, and the seeds of *Luzula* are all easily referred to their proper places, as well as the leaves and stems of all the plants except the grasses. The characters of the leaves of the grasses are various, and are found in their texture, surface, colour, point, ligule, mode of curling or folding together when dry, nature of the margin, colour and relative prominence of the midrib, &c. By one or more of these characters it is possible to distinguish pieces not more than a quarter of an inch long—in fact, almost any piece with two ends. With regard to the influence of the manures on the botanical characters, or any of the characters I have indicated, it appears to be very slight throughout the whole series of experiments. It is mainly limited to the vigour, and consequent size of the plant, and the degree of hairiness. That is to say, it is possible to divide the species represented on the plots into those with constantly hairy and those with constantly hairless leaves. The hairs may be exceedingly minute, and only visible in a certain position, as on the upper surface of the folded leaves of *Poa pratensis*, or more or less prominent on both surfaces, as on the hard leaves of *Avena pubescens*, and on the soft leaves of *Holcus lanatus*—the “Hard Hairy” and “Soft Hairy” of the boys. *Avena flavescens*, *Bromus*, and *Anthoxanthum* present different kinds of hairs, difficult to describe but facile to distinguish. Thus it becomes intelligible that, beginning with the less complex samples, and knowing what species grow on the plots whence they were taken, it is not so formidable a task as one might suppose. But it is tedious in the extreme when a handful of small stuff will keep one busy for a day or two.

The object of this brief sketch of the experiments on permanent grass-land at Rothamsted is not so much to make them more widely known as to offer sufficient information to botanists as to render the experiments themselves more intelligible and interesting to those who are obliged to be content with paying an occasional flying visit. Anyone desirous of obtaining more exact details of the plan and extent of the experiments will find what they want in the papers and reports referred to above, and Mr. Lawes has in preparation a full report of the results of these experiments, in which the whole subject will be as exhaustively treated as available data will permit.
