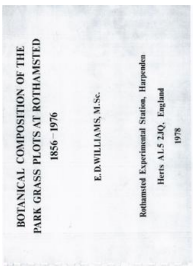
Botanical Composition of the Park Grass Plots at Rothamsted 1856-1976



Full Table of Content

Results

Rothamsted Research

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analysed from each sub- or half-plot.

The plots sampled in the four years were as follows:-

(1) 1973 – sub-plots *c* and *d* of plots 1 (N_1), 4^2 (N_2P), 9 ($N_2PKNaMg$), 10 (N_2PNaMg), 11^1 ($N_3PKNaMg$), 11^2 ($N_3PKNaMgSi$) and 18 (N_2KNaMg), i.e plots receiving N as ammonium sulphate.

(2) 1974 – sub-plots *a* and *b* of plots 4^2, 9, 10, 11^1 and 11^2 and also sub-plots 13*c* and 13*d* (FYM and fish meal).

(3) 1975 – unlimed (U) and limed (L) half-plots of plots 3 (unmanured), 7 (PKNaMg), 8 (PNaMG), 14 ($N_2^*PKNaMg$), 16 ($N_1^*PKNaMg$) and 17 (N_1^*).

(4) 1976 – unlimed (U) and limed (L) half-plots of 3, 7, 14 and sub-plots *a, b* and *c* of plot 9.

The dates of sampling in 1973, 1974, 1975 and 1976 were respectively 12, 20, 9 and 9 June.

As in 1948 and 1949 about 1-2% of the samples consisted of small detached fragments which were not sorted into species. Although it would have been technically possible to do so it would have taken too much time. To maintain continuity with past records the contribution of each species was expressed as a percentage of the total hay (air dry) weight of the sample. However, yields since 1960 have been based on dry weight before hay-making and it is possible that the contribution to dry weight may differ slightly from that to hay weight. Since yields of many plots differ greatly the % figures have nevertheless been used to calculate the weights of the different species per unit area to provide a measure of quantitative as well as qualitative difference between plots (see Tables 39, 41, 43 and 45).

The two main aims of this paper – to present recent data on the botanical composition of some of the main plots and at the same time to trace the major changes that have occurred on them with time and to report on the effects of the new liming scheme – are considered separately.

RESULTS

1. CHANGES WITH TIME

A. PLOTS NOT RECEIVING NITROGEN

1. **Unmanured plots** [3, 12 (since 1856) and 2 (since 1863)]

Although most treatments are neither randomised nor replicated two plots, 3 and 12, at different ends of the field have received no fertiliser from the start. However, Lawes, Gilbert & Masters (1882) considered plot 3 to be the true 'control' plot since they deduced that soil had in the past been brought in to plot 12 to level this part of the field. The soil of plot 12 has differed in chemical composition from plot 3 and yielded more hay for most of the duration of the experiment (Warren & Johnston, 1964). Plot 2 has received no manure since 1863 and so can now also be considered an unmanured plot.

The botanical composition of Plot 3 in 1858 (Lawes & Gilbert, 1859), is a reasonable indication of the flora of the whole field at the start of the experiment. About twenty species of higher plants were identified on the plot in 1858 but during 1862 about fifty species were found "a result no doubt due to the much greater amount of attention and labour bestowed upon the more recent separations" (Lawes & Gilbert, 1863). During 1877-1903 a decline in the number of species then occurred and between 1910 and 1948 the number of species identified averaged about 37. Thirty species were found in 1975 and 35 in the 1976 samples, but since the range of variation for

https://doi.org/10.23637/ERADOC-1-156

previous years was from 25 to 41 there is no evidence of any change in the number of species during the last 30 years.

The relative contributions of grasses, legumes and other species have changed during the duration of the experiment [Table 7(a)] as well as the composition of the three main groups themselves (Table 8). Grasses contributed 76% of the yield on plot 3 at the start and other species less than 20% and these proportions remained unchanged for about thirty years. Afterwards % grasses decreased, averaging 53%, and other species increased to about 40%, but seasonal variations have been large. At the same time yields declined by about 50% so that the net amount of grass greatly decreased but other species remained much the same. Legumes have ranged from 2 to 19% but usually 5 to 12% and averaged 7%; they have not changed systematically with time. The most plentiful grasses at the start were *Lolium* and *Holcus* which together contributed about a third of the herbage. *Arrhenatherum, Anthoxanthum, Agrostis* and *Festuca* all contributed at least 5%. *Lolium* and *Arrhenatherum* then declined and since 1877 have not made a significant contribution to yield. *Anthoxanthum* remained much the same but *Agrostis* increased as also did *Festuca rubra* and these have been the two main grass species throughout. *Festuca rubra* has increased markedly since the last hay analysis in 1949 and grasses now contribute more than 60% to the yield. Amongst the legumes, *Lotus* has usually been the main constituent; *Lathyrus* was not prevalent during 1975 and 1976 but similar results were obtained in 1938 and 1939. (Table 8). Although a large number of other species still persists the most significant change has been a tendency of three species to be dominant within this group. *Poterium*, present in small amount, and *Leontodon*, absent at the start, have been abundant from the beginning of the century. *Plantago* has also been plentiful throughout but has fluctuated systematically from only 3% between 1872 and 1914 to about 13% from then until 1939 and afterwards about 6%. *Ranunculus* species, 2-5% in the early years have been less conspicuous since then, but *Centaurea* increased from a small amount to 2-10% between 1903 and 1939 but afterwards declined. It is of interest to note that, although the weather preceding the 1976 harvest was much drier than that preceding the 1975 harvest, *Plantago* and *Poterium* were no more abundant in 1976 than in 1975. This contrasts with results in 1937 and 1938, with similar sequences of weather, when the % of both species was two-three times greater in 1938 than in 1937.

Plots 2 and 12, not analysed during 1973-76, have also been analysed much less frequently than plot 3 in the past; in general their botanical composition has been very similar to that of plot 3 (Tables 9 and 10). One of the main differences is that both have little *Poterium.*

Liming on plot 3 initially increased % grasses and decreased % other species, compared with the unlimed half-plot [Table 7(a)] . However, % grasses have declined and % other species increased with time so that there is now a greater percentage of grass but a smaller percentage of other species on the unlimed than on the limed half-plot. Percentage legumes was increased by lime and appeared to increase until about the mid-40's. The number of species has been little affected by lime; there has possibly been a slight increase. Lime soon increased *Helictotrichon* and *Briza* and decreased *Agrostis* (Table 11). Percentage *Briza*, although usually greater on the limed than on the unlimed half-plot, declined from about the mid-20's onwards and *Helictotrichon* has also declined more recently. *Festuca*, almost as plentiful on the limed as on the unlimed half-plot until about the mid-20's, declined more on the limed than on the unlimed half-plot and it has usually been more plentiful on the unlimed half-plot.

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Recently *Festuca* has also increased on the limed end. *Trifolium pratense* has increased since the mid-1930's. Amongst the other species the same three species have been abundant as on the unlimed end. However, lime decreased the percentage of all of them until around 1940. Afterwards % *Poterium* and *Plantago* have been greater on the limed than on the unlimed half-plot and during 1975 and 1976 % *Leontodon* was also larger on the limed than on the unlimed half.

Plot 4[1] (Table 12) which has received P alone since 1859 and has been only infrequently analysed was not included in these analyses. It has usually had a smaller % *Agrostis* and *Poterium*, but a larger % legumes and *Rumex* than the unmanured plots.

2. **PKNaMg** (Plot 7)

As on plot 3 (unmanured) % grass declined on this plot after the first 25 years or so and % other species increased slowly from the outset to reach about 30% by the mid-1940's [Table 7(a)]. The main difference between this and the unmanured plots in the three main groups of plants has been a much larger % legumes in most seasons. Even in the third year legumes, mainly *Trifolium pratense*, were 23%, but afterwards *Lathyrus* has been the main component of this group (Table 13). The 1975 and 1976 analyses show that, as on plot 3, % grasses have recently increased, % legumes and other species have decreased. This conclusion, although based on results from two contrasting seasons, must, nevertheless, remain a tentative one since the recent values are within the range of variation recorded in the past. Visual surveys, however, during the past ten years have also suggested a decline in the legumes on this plot.

Dactylis increased on this plot during the beginning of this century (Table 13), and made a much larger contribution to the yield of this than of the unmanured plot. The 1975 and 1976 analyses showed that it declined between 1948 and these dates but was still twice as plentiful as on plot 3. Percentage *Agrostis* and *Festuca* have usually been less on this plot than on plot 3 but both have increased tremendously since 1948 so that about half the herbage here, as on the unmanured plot, now consists of these two species. In contrast to the unmanured plot, where it has recently decreased, *Holcus* has increased on this plot.

The recent decline in legumes has been mainly in *Lathyrus; Trifolium pratense* has remained at the same level as in 1947-48. *Achillea* and *Heracleum* have usually been more prominent here than on the unmanured plot but both now contribute only 1% or less of the herbage. The large amount of *Achillea* recorded during 1947 and 1948 did not persist. *Poterium* and *Leontodon*, important constituents of the unmanured plot, are absent or infrequent on this plot but since 1947 *Plantago* has increased and it is now as abundant as on the unmanured plot 3. *Rumex* has been more conspicuous on this plot than on the unmanured plot, although it has declined greatly on both plots.

On the limed half of this plot grasses have contributed about 60% of the yield but have ranged from less than 40 to more than 80%, and during 1975 and 1976 were respectively 48 and 40% [Table 7(a)]. Legumes have also ranged widely, averaging about 25% and other species, about 12%. There have been no definite trends with time within the three main groups. However, within the grasses, *Arrhenatherum* has increased with time, especially during the last 30 years, and now makes up 30% of the herbage, but *Alopecurus* and *Dactylis* both prominent throughout have decreased during the same interval as also have *Helictotrichon* and *Trisetum* (Table 14). *Festuca rubra*, much decreased by lime, further decreased with time so that it now contributes less than 1% of the herbage. Both *Poa* species have maintained their contribution. *Lathyrus*

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although variable between seasons has also probably maintained its contribution and was abundant in 1976. *Trifolium pratense* increased from the mid-30's but *T. repens*, which was then conspicuous, is now infrequent. The most abundant other species are now *Taraxacum, Heracleum* and *Ranunculus* but their % contribution was much larger in 1975 than in 1976. *Heracleum* increased about fifteen years after liming but the increase in *Taraxacum* has been more recent. *Centaurea* and *Knautia* are now less abundant than in the past.

Plot 15 (Table 15) received 96 kg N ha^{-1} as sodium nitrate until 1875 but since then it has received the same treatment as Plot 7. Legumes, which were present in only small amounts when only nitrogen was given, quickly reappeared and were 10% by 1880, almost 20% during the next ten years and about 40% between 1891 and 1900. The level then decreased somewhat but with large seasonal variations. The reappearance of legumes on this plot was faster than where the same amount of nitrogen as ammonium sulphate was replaced by PKNaMg (original Plot 6). Plot 15 has had more *Alopecurus* and *Dactylis* than Plot 7 throughout most of the experiment. However, strict comparisons between the limed halves of the two plots cannot be made for particular years since liming started 17 years later on Plot 15 than on Plot 7. As on Plot 7 liming encouraged *Arrhenatherum* but *Dactylis* has usually been less plentiful on 15 than on 7. *Trifolium repens* has been more abundant on the limed half of 15 than on 7.

3. **PNaMg** (Plot 8)

This plot also received K and sawdust during 1856-61 and 1856-62 respectively. Omitting K had large effects on % legumes and on yield; in most years there has been 20-25% less legume on this plot than on Plot 7 (PKNaMg); the reduction was even larger in the early years. Recently, because of the decline on Plot 7, % legumes have been similar on the two plots. Percentage grass has usually been less and other species much more than on the PKNaMg plot [Table 7(a)] ; there have been more species on this than on the PK plot but slightly fewer than on the unmanured.

This plot has a smaller percentage of *Agrostis* than the unmanured and PKNaMg plot since c. 1930; as on those plots *Festuca rubra* has been plentiful throughout and although there was some evidence of decline in the late 40's it had also increased by the time of the recent analyses (Table 16). *Arrhenatherum*, although recently declined has been more prominent than on the unmanured or PK plot, but *Dactylis* has, except in 1947 and 1948, been less abundant than on the PK plot. A marked permanent decline in *Lathyrus* occurred during the 1920's and the legumes now consist mainly of *Trifolium* and *Lotus. Plantago* has contributed 10-30% since the beginning of the century and *Leontodon* is also prominent and possibly increasing, but *Achillea* was much less prominent in 1975 than in 1948.

The botanical composition of the limed half is qualitatively similar to that of the unlimed half (Table 17). The main difference is that *Helictotrichon* is much more abundant with than without lime. As on the unlimed half *Arrhenatherum* and *Dactylis* have recently decreased but *Anthoxanthum* and *Festuca rubra* increased and *Plantago* and *Leontodon* are the main other species.

B. PLOTS RECEIVING NITROGEN AS AMMONIUM SULPHATE

Some of the most spectacular treatment effects on Park Grass and some of the largest changes with time have been due to the acidifying effect of ammonium sul-

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phate. All the unlimed sub-plots of plots given ammonium sulphate are now dominated by acid-tolerant grasses.

Three plots in this group were omitted from the main experiment in 1964. One of them (original Plot 6) received N_2 and sawdust until 1868 and the other two (Plots 5^1 and 5^2) received N_2 alone until 1897. The nitrogen dressings, which were very damaging to the herbage, were replaced by PKNaMg on Plot 6 from 1869, PK on Plot 5^2 from 1898 but not replaced by anything on 5^1 from 1898, which remained an unmanured plot until 1964. Details of the botanical composition of these plots are given by Brenchley & Warington (1958).

1. N_1 (Plot 1)

Plot 1 received farmyard manure during the first eight years; thus comparisons of its botanical composition in 1862 with that of Plot 2 (farmyard manure alone 1856-63) show the effect of a small amount of N in the presence of FYM: the main effect of the additional nitrogen was to increase *Dactylis* but slightly decrease *Lathyrus*.

This plot consisted of about 80% grass in the second year and grasses ranged from 78 to 95% during the next 60 years or so [Table 7(b)]. Legumes, which ranged seasonally from 0.2 to 3%, were absent from c. 1910 onwards although traces were present in the early 1940's. Most of the variation in % grasses was therefore counterbalanced by variations in other species. Nowadays, % grasses is about 98% and other species have seldom exceeded 5% during the last thirty years. During the first 20 years *Dactylis* and *Poa trivialis* declined and *Agrostis* and *Anthoxanthum* increased (Table 18). *Holcus*, after apparently declining between the second and sixth year, also increased. During the 1920's and 1930's *Anthoxanthum* and *Holcus* were reduced to very small amounts but *Agrostis* continued to increase as also did *Festuca*. The last two species were co-dominant in 1939 and in 1940 72% of the herbage consisted of *Festuca*. By the late 1940's, however, *Agrostis* was dominant and has remained so ever since. The recent analysis in 1973 showed a further decrease in *Festuca* but a substantial increase in *Anthoxanthum*.

Liming this plot increased *Helictotrichon* and *Dactylis*, and allowed a small amount of legume to flourish and also many other species, especially *Plantago* (Table 18).

2. N_2 **KNaMg** (Plot 18)

This treatment has been applied to Plot 18 since 1905 following PKNaMgSi and an amount of N (16 kg) equal to that contained in 1.02 t hay. In the absence of P and with acid soil conditions *Agrostis* became dominant on this plot and possibly sooner than on Plot 1 although treatment on that plot started in 1863. *Dactylis* rapidly decreased and *Festuca* more slowly so that there was none of the former and little of the latter present in 1973 (Table 19). Both light and heavy liming greatly encouraged *Dactylis* and continue to do so, and *Alopecurus* was also increased initially but it declined during the 30's and early 40's. As *Alopecurus* declined *Arrhenatherum* increased with both light and heavy liming (Table 20).

3. N_2**P** (Plot 4^2)

Festuca rubra has been the most abundant grass on this plot for most of the duration of the experiment and it was co-dominant with *Agrostis* in 1949 (Table 21). *Agrostis* was abundant from the start and has maintained its contribution. *Anthoxanthum* became prominent from the beginning of the century and greatly increased during the 1950's and 1960's; it is now dominant (76%) on the unlimed quarter-plot but *Festuca*

https://doi.org/10.23637/ERADOC-1-156

is infrequent. *Alopecurus* was the most plentiful grass for about 20 years following liming; it then decreased and *Festuca*, which now makes up about half the herbage, increased. *Poa pratensis* was also plentiful in 1974.

4. **N_2PNaMg** (Plot 10)

Like the other plots given nitrogen, this plot has also been dominated by grasses [Table 7(b)] except in the early years and during 1915-1920, when *Rumex* was abundant. *Dactylis, Helictotrichon, Poa pratensis* and *Poa trivialis* all declined during or shortly after the first twenty years. *Festuca rubra* increased during the same time, but except in 1948, did not make a very large contribution after 1920. The most important grasses on this plot during the last 40-50 years have been *Agrostis, Anthoxanthum* and *Holcus* and these have competed for dominance. *Holcus* became dominant probably sometime during the 1920's and remained so until 1938 but afterwards it declined greatly; *Anthoxanthum* and *Agrostis* together with *Holcus* made up 90% of the herbage in roughly equal proportions in 1940. Afterwards *Holcus* decreased, *Agrostis* remained plentiful and *Anthoxanthum* has been dominant for ten to fifteen years (Table 22).

Lime not only prevented *Alopecurus* declining but increased it so that it was dominant until c. 1940; afterwards its contribution was halved but *Festuca rubra* previously 20-30% increased to about 50% during the 1940's. Recently, *Alopecurus* has decreased further and *Arrhenatherum* and *Anthoxanthum* have increased (Table 23).

5. **N_2PKNaMg** (Plot 9)

This plot has been analysed more frequently than any other. By the third year *Holcus* and *Lolium* had doubled their contribution to a total of 69% (Table 24). Both subsequently decreased, *Holcus* temporarily, but *Lolium* was absent after 1903. *Dactylis* also declined from about 13% in the 1870's to less than 1% in the mid-20's and *Festuca rubra* which made a significant contribution until the mid-20's also later declined. *Arrhenatherum*, prominent between 1870 and the mid-20's was afterwards much reduced. Between 1900 and 1930 a struggle for dominance occurred between *Agrostis, Anthoxanthum* and *Holcus*; by 1921 they contributed 80% of the herbage in approximately equal proportions. However, by the mid-20's *Holcus* became increasingly ascendant and was dominant from 1930 probably until about 1962. Since then *Anthoxanthum* has been dominant on the unlimed sub-plot. Legumes have always been absent and after the first 60 years other species have rarely contributed much to the yield of this plot.

Alopecurus and *Arrhenatherum* have usually dominated the limed half of this plot, although several other grasses particularly *Dactylis, Festuca, Holcus* and *Poa pratensis* have also made significant contributions (Table 25). *Arrhenatherum* became prominent sooner and was twice as abundant as *Alopecurus* during the first four cycles of the liming scheme. From the late 1920's until 1940, except in 1932 and 1933 *Alopecurus* contributed about 50% of the hay yield and was usually much more abundant than *Arrhenatherum*; it continued to be so during 1947 and 1948 although both species were much reduced in those years. The evidence available in 1974 and 1976 suggests that whereas *Alopecurus* declined further, *Arrhenatherum* increased and there is now at least three times as much *Arrhenatherum* as *Alopecurus* on this plot. Recently, *Festuca* and *Poa pratensis* have decreased but *Holcus* increased.

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Small amounts of *Lathyrus* were present on this plot in most years in the past and the amount increased during the late 1930's and 1940's; it is now abundant (Table 25). As on the limed half of Plot 7 (PKNaMg) the species was unusually abundant during 1976. Before 1940 other species rarely contributed more than 4% to the yield but since then they have ranged from 4 to 14%, the increase being mainly in *Heracleum* and *Taraxacum*.

6. **N_3PKNaMg** (Plot 11^1) **and N_3PKNaMgSi** (Plot 11^2)

On Plot 11^1 (with the largest amount of ammonium sulphate) *Alopecurus* and *Arrhenatherum* increased slowly to reach about 30% in 1903 and 1919 respectively. Both species then declined to very small amounts. Percentage *Dactylis* doubled during the first ten years, then decreased to its original level between 15 and 20 years and then virtually disappeared. Neither *Poa* species, both about 10% at the start, persisted. Neither *Lolium* nor *Holcus* were as much encouraged in the early years as on Plot 9, with a smaller amount of N. In fact, *Holcus* declined during the early years, but then increased greatly as *Alopecurus* and *Arrhenatherum* declined. It has been dominant on this plot since c. 1910 (Table 26). *Agrostis*, encouraged during the early years, has not persisted on this plot to the same extent as on the plots receiving N_2. *Anthoxanthum* has been present in only small amounts; in 1973 it made up 5% of the herbage and appears to be increasing. Except during the early years, or in exceptional seasons, only small amounts of other species have occurred on this plot. The botanical composition of Plot 11^2, which receives Si as well, has been similar to 11^1 except that *Holcus* probably became completely dominant later. *Alopecurus* contributed 30% to the yield of this plot in 1919 whereas it had declined to 1% on 11^1 by 1914. *Arrhenatherum* also persisted for longer on 11^2 than on 11^1 (Table 27).

As on the plot receiving N_2 (96 kg N ha^{-1}) and PKNaMg, *Alopecurus* and *Arrhenatherum* are the most abundant grasses on the limed end of these plots. Without silica (Plot 11^1) *Alopecurus* and *Arrhenatherum* were equally abundant in 1914, 11 years after the start of liming. *Alopecurus* then increased and *Arrhenatherum* decreased markedly. Afterwards *Alopecurus* decreased and *Arrhenatherum* increased so that they were again present in roughly equal proportions in 1974. On 11^2 *Alopecurus* was twice as abundant as *Arrhenatherum* in 1914 and a similar sequence of events occurred but on a different scale so that in 1964 there was almost twice as much *Arrhenatherum* as *Alopecurus*. There has, for most of the time, been more *Dactylis* on 11^2 than on 11^1. Although *Poa pratensis* has declined *Poa trivialis* has increased. A large increase in *Holcus* has occurred on both plots since the 1947 and 1949 analyses. *Taraxacum* established on these plots during the 1940's and since then *Anthriscus*, *Heracleum* and *Rumex* have increased slightly.

C. PLOTS RECEIVING NITROGEN AS SODIUM NITRATE

These plots were started in 1858. Plot 15 (already discussed) which has received PKNaMg since 1876, received 96 kg N ha^{-1} as sodium nitrate annually between 1858 and 1875.

1. N_1 (Plot 17)

The botanical composition of this plot contrasts strongly with that of Plot 1, which receives the same amount of nitrogen, but as ammonium sulphate. Grasses have usually contributed about 70% and other species 30% to the yield of plot 17 but legumes only

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a trace [Table 7(c)]. About 30 species of plants occur on this plot. There has, with the possible exception of *Anthoxanthum*, been no large or permanent increase in the acid-tolerant species: the plot now has less *Holcus* than in the past and there is less *Agrostis* than at the outset (Table 28). *Alopecurus* contributed almost a quarter of the yield at the start and also in 1976 but about 10% less than this in most of the intervening years. *Dactylis* increased during the first decade of the century and was abundant from 1925 to 1949 but declined sometime between that time and 1975, when it was 5%. *Festuca rubra* has been the other main grass. A small amount of *Lolium* has persisted on this plot. There have been few legumes. *Plantago* has been the main other species throughout. *Leontodon* increased at the beginning of the century and was 4% in 1975 as also was *Ranunculus.*

The vegetation on the limed half of this plot (Table 29) has been relatively stable although *Festuca* has decreased recently. A larger percentage of *Lolium* was recorded on this plot than on any other plot in recent years and more *Trifolium pratense* was also present than in the past. As on the unlimed half plot *Plantago* and *Leontodon* are the main other species.

2. **N_1PKNaMg** (Plot 16)

About 80-90% of this plot consists of grass. Legumes have been variable ranging from about 2 to more than 10% and other species about 10% [Table 7(c)]. The plot now has about 20 species. *Festuca, Helictotrichon, Holcus* and *Trisetum*, all prominent during the early years, afterwards declined. *Alopecurus* increased greatly during the first 60 years and was 51% in 1919; it then declined and was 29% in 1975. At the same time *Arrhenatherum* increased so that the two species are now co-dominant (Table 30).

On the limed half of this plot *Arrhenatherum* increased much as on the unlimed half. *Alopecurus* which was equally abundant on both half-plots in 1914 afterwards declined earlier and to a greater extent on the limed half so that it was only 4% in 1975 (Table 30). *Festuca* and *Helictotrichon* were much reduced in 1975 compared to 1949. The main recent change in other species on the limed half has been a very large increase in *Heracleum. Ranunculus* and *Taraxacum* have also increased.

3. **N_2PKNaMg** (Plot 14)

This plot has had a large percentage of grass and usually has less legume and other species than Plot 16 [Table 7(c)]. It has also had slightly fewer species.

As with the smaller amount of sodium nitrate *Alopecurus* quickly increased and as on that plot was 50% of the herbage in 1919. It remained at a high level (35-62%) during the next 20 years, declined to c. 30% during the late 1940's but had increased slightly again by 1975 and 1976. *Arrhenatherum* established sooner and had in fact reached 41% on this plot before starting to increase on Plot 16 (N_1PKNaMg); it has been co-dominant with *Alopecurus* especially since the late 1940's. The amounts of *Anthriscus* and *Taraxacum* have fluctuated throughout the course of the experiment (Table 31).

Liming this plot more than halved % *Alopecurus* from about the fourth year onwards but increased % *Arrhenatherum* from the fifth year onwards (Table 32). The amount of *Alopecurus* was further reduced in the 1940's. *Dactylis* has decreased as also has *Festuca rubra*, and *Anthriscus* and *Taraxacum* have fluctuated as on the unlimed half. Details of the differences between the botanical composition of parts of the plot in the sun and in the shade are outlined by Brenchley & Warington (1958) –

https://doi.org/10.23637/ERADOC-1-156

in general *Dactylis* and *Arrhenatherum* were less but *Festuca rubra* much more abundant in the shade than in the sun.

D. PLOTS RECEIVING ORGANIC MANURES

None of the plots now receiving farmyard manure (FYM) have the treatment dating back beyond 1905. Plot 13 which has received FYM and fish meal alternately once every four years since 1905 received N_2 (as ammonium sulphate) and PKNaMg between 1856 and 1904 and straw until 1897. Plot 19 which has FYM once every four years received N_1 (as sodium nitrate) and PK between 1872 and 1904. Plot 20 which also received N_1 (N as potassium nitrate and PK) during the same period also now receives FYM every fourth year but also N (30 kg ha^{-1} as nitrate of soda), P (15 kg ha^{-1} as superphosphate) and K (45 kg ha^{-1} as sulphate of potash) in intervening years.

Plot 13 was included in the liming scheme of 1903 and is now in the new one. Plots 19 and 20 (like 18) were divided in 1920 into lightly, heavily and unlimed thirds to test two laboratory methods for measuring the lime requirement of soils. (Warren & Johnston, 1964). They are not included in the new liming scheme and were not analysed during 1973-76. They were, however, unlike the plots in the main liming scheme, analysed in the years immediately after liming and so provide evidence of the rate of change in different constituents after liming, not available from any other plots. For this reason past results for these two plots are also included (see also Brenchley, 1925 and 1930).

1. **FYM and fish meal** (Plot 13)

The main species on the unlimed end of this plot has for most of the time been *Alopecurus*. It increased until the mid-40's to c. 50%, then declined to 16% in 1974. *Agrostis* increased in the mid-40's and was twice as abundant as *Alopecurus* in 1973 and *Holcus* has increased markedly since 1949 (Table 33).

Alopecurus was increased by lime in 1919 but then declined to less than on the unlimed half. *Arrhenatherum* was also increased by lime in 1914 but then declined before increasing to become the most plentiful grass in 1948. Although lime had only small effects on *Dactylis* in the early years it greatly increased it during 1946-48 so that it contributed more than 20% in those years. With lime *Agrostis, Anthoxanthum* and *Festuca* are infrequent and *Holcus* now much reduced. Legumes, although variable between seasons were plentiful on the limed half. *Plantago* has been the main other species, although it was much reduced on the unlimed half in 1974 (Table 33).

2. **FYM every fourth year** (Plot 19)

Although *Alopecurus* was slightly more prominent than most other species it declined during the 30's and for most of the time there has been no single dominant. Legumes have been plentiful but variable, and although *Plantago* was the main other species during 1946-48 there was also much *Ranunculus* and *Achillea* (Table 34).

Lime had little effect on *Alopecurus* until the ninth year when low lime increased but high lime decreased it (Table 35). Afterwards during 1946-48 both amounts of lime increased *Alopecurus*. The effects of lime on *Dactylis* depended upon the season: in many years there was little effect but in others there were large (and similar) increases with both amounts of lime. *Festuca rubra*, little affected at the start, was usually decreased by lime although high lime increased it during the eighth and ninth years. High lime decreased *Agrostis* from the fifth year onwards but low lime had little

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effect during the first 20 years.

Liming, especially the larger amount, decreased *Anthoxanthum* and *Holcus* but increased *Helictotrichon* and *Trisetum.* The amount of legume, although somewhat increased by lime, has been more dependent upon season than upon the liming treatment. The main other species have been *Plantago, Ranunculus* and *Achillea.* Neither % *Plantago* nor the time of its increase have been affected by lime, *Achillea* was little affected by low lime and decreased by high lime whereas *Ranunculus* was increased by low lime but decreased by high lime.

3. **FYM once every four years with NPK in other years** (Plot 20)

As on Plot 19 (FYM alone), *Alopecurus* has tended to be the main grass species on this plot but *Dactylis* and *Arrhenatherum* have also been prominent (Table 36). In contrast to Plot 19, where it declined during the 1940's *Alopecurus* remained at a high level on this plot. Although lime, especially the larger amount, increased % *Alopecurus* until 1925, it afterwards decreased it. In contrast, *Arrhenatherum* was decreased by both amounts of lime during the first three years; afterwards the smaller amount increased it but there was no increase with the larger amount until 1946-48. The effect of lime on *Dactylis* was small and somewhat erratic, and the larger amount tended to decrease it. *Poa pratensis* was decreased by the smaller but increased by the larger amount of lime though *Poa trivialis* was increased by both amounts. *Helictotrichon* has declined on all sub-plots of Plot 20; it was decreased by low lime at the start but then increased though high lime increased it throughout. In contrast *Trisetum*, decreased by both rates of lime at the start, was afterwards little affected. Both rates of lime decreased *Agrostis* but not *Holcus. Lathyrus* has varied greatly with season and has been increased by high lime throughout (Table 37).

Plantago, prominent in the late 40's was increased by both amounts of lime but *Achillea* little affected by low lime was increased by high lime. *Taraxacum* was also increased by lime.

2. CHANGES INDUCED BY THE NEW LIMING SCHEME

A. EFFECTS OF APPLICATIONS OF LIME BETWEEN 1965 AND 1968 ON THE BOTANICAL COMPOSITION OF PREVIOUSLY UNLIMED SUB-PLOTS *c* COMPARED WITH THAT OF SUB-PLOTS *d* (CONTINUOUSLY UNLIMED) OF PLOTS GIVEN AMMONIUM SULPHATE i.e. 1, 4^2, 9, 10, 11^1, 11^2 AND 18 AND OF 13 (FYM AND FISH MEAL)

To assess the effects of fresh applications of lime to previously unlimed sub-plots *c*, samples of herbage were taken for botanical analyses in 1973 from the relevant sub-plots and also from the corresponding permanently unlimed sub-plots *d* of the same plots. Although the plots were not sampled for botanical composition prior to the introduction of the new scheme in 1965, visual survey showed no changes in the flora of sub-plots *d* between 1965 and 1973. Since these sub-plots are dominated by single species, the botanical compositions of sub-plots *d* in 1973 may be taken as a measure of the composition of both *d* and *c* (i.e. the unlimed half-plot) at the start of the new liming scheme.

Since liming affected total dry matter yield at hay making as well as botanical composition, results are expressed not only qualitatively as % composition of hay but also quantitatively as amounts ha^{-1} as explained in the Introduction.

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1. Plots 1 (N_1) and 18 (N_2KNaMg)

The unlimed sub-plots of both plots 1 and 18 were dominated by *Agrostis* at the start of the new liming scheme and sub-plot *d* of both plots had more than 80% *Agrostis* in 1973. By 1973, 12.5 and 10 t ha^{-1} of calcium carbonate had decreased this species from 84 to 20% on 1c and from 83 to 52% on 18c (Table 38). *Anthoxanthum*, which contributed c.10% on 1 and 20% on 18, was less affected. The most obvious changes were extremely large increases in % *Festuca rubra* on both plots (from 3 to 50% on 1 and from 0.1 to 14% on 18) and the introduction or increase of a large number of other species including *Cerastium, Plantago, Rumex* and *Taraxacum* on both plots. *Lathyrus* and *Trifolium* also established on both plots but in greater amount on 1 than on 18, *Lathyrus* having spread inwards from adjacent Plot 14.

Since liming increased the yield of *c* relative to *d* approximately threefold on both plots in 1973, the effects on the amount of species per unit area of land (Table 39) differed from those on percentage composition (Table 38). For example, the large reduction in % *Agrostis* on 1*c* compared to 1*d* was largely offset by the increase in yield and on 18*c* the relatively smaller decrease in % *Agrostis* was more than counterbalanced by the increased yield so that there was almost twice as much *Agrostis* on 18*c* as on 18*d*. On the other hand, increases in % composition of particular species e.g. *Festuca* were greatly accentuated by the yield increases.

2. Plots 4^2 (N_2P), 10 (N_2PNaMg) and 9 (N_2PKNaMg)

The unlimed half-plots of these three plots were dominated by *Anthoxanthum* at the start of the new liming scheme in 1965 and the unlimed sub-plots *d* continue to be so (Table 38). About 20 t ha^{-1} of chalk, applied to these sub-plots between 1965 and 1968, decreased % *Anthoxanthum* from more than 70% to between 5 and 11%. The yield of hay was at the same time increased by at least 50% but the reduction in the amount of *Anthoxanthum* was nevertheless at least 80% (Table 39). In contrast to *Anthoxanthum* and to *Agrostis* in the previously discussed plots, % *Agrostis* on these plots was less affected by liming. However, on Plot 10*c* the combined effect of a small increase in % *Agrostis* and the 50% increase in total yield resulted in a large increase in the amount of this species. Liming allowed a range of grasses to increase or to establish. On Plots 4^2c and 10*c*, in the absence of potash, *Festuca rubra* increased greatly to form about half and a quarter of the total yield respectively; on 9*c* which receives potash, *Festuca* increased much less and formed only 3% of the total yield. *Holcus* increased greatly on 9*c* and 10*c* and *Poa pratensis* increased on all three sub-plots.

There was some evidence that *Holcus* increased further between 1973 and 1976 on 9*c* as also did *Arrhenatherum* (Tables 44 and 45). Only on 9*c* did legumes and appreciable amounts of other species establish.

3. Plots 11^1 (N_3PKNaMg) and 11^2 (N_3PKNaMgSi)

The unlimed half plots of 11^1 and 11^2 were dominated by *Holcus* in 1965 and sub-plots *d*, permanently unlimed, continue to be so. Twenty t ha^{-1} of chalk, applied between 1965 and 1968 have resulted in very similar changes in the botanical composition of both sub-plots. Percentage *Holcus* was decreased from 96 to 34% (Table 38) and the weight was, on average, halved (Table 39).

In 1973 *Arrhenatherum* contributed about 30%, *Poa pratensis* 12%, *Alopecurus* 8%

8R

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and *Dactylis* 6% on sub-plots *c* but were absent on sub-plots *d*. No legumes were present in the samples from either plot in 1973 although visual survey had indicated that a few plants of *Trifolium pratense* were present on $11^2 c$ between 1966 and 1969. Liming allowed small amounts of *Anthriscus, Cerastium, Heracleum, Rumex* and *Taraxacum* to establish.

4. **Plot 13 (FYM and fish meal)**

The main effect of lime on this sub-plot has been to increase *Arrhenatherum* and the legumes, *Lathyrus* and *Trifolium pratense* and to decrease *Agrostis* and *Holcus*. Lime also appeared to have relatively large effects on some of the other species but since their individual contribution rarely exceeded 1% confirmation of the changes would be needed in other years. (Tables 38 and 39).

B. EFFECTS OF INCREASED APPLICATIONS OF LIME BETWEEN 1965 AND 1968 ON THE BOTANICAL COMPOSITION OF SUB-PLOTS *b* (WHOSE pH IS BEING RAISED TO 6) COMPARED WITH THAT OF SUB-PLOTS *a* (LIMED ONCE EVERY FOUR YEARS UNDER THE OLD SCHEME TO MAINTAIN pH AS IN 1965) OF PLOTS 4^2, 9, 10, 11^1 and 11^2.

As might be expected, increasing the rate of liming on previously limed sub-plots has effected fewer changes in botancial composition than liming sub-plots previously unlimed.

On plots $4^2 b$ and 10*b* whose pH was previously more than 5.5, only 3.7 t ha^{-1} of calcium carbonate were needed to raise the pH to 6 and this caused few changes in botanical composition. The only significant change was a large increase in both percentage and weight of *Helictotrichon* on $4^2 b$. Both *Plantago* and *Rumex* appeared to be increased by increased lime on $4^2 b$ but not on 10*b* (Tables 40 and 41).

Sub-plot 9*b* was slightly more acid than $4^2 b$ and 10*b* and was given twice as much lime (7.5 t ha^{-1}) to increase the pH to 6. The main effects of this in 1974 were to halve the % (Table 40) and weight (Table 41) of *Alopecurus* and to increase the legumes, particularly *Lathyrus*. Sub-plots 9*a* and 9*b* were again analysed in 1976. It is likely, however, that sub-plot *b* would still be in a state of change and sub-plot 9*a* received 14 t ha^{-1} of chalk in 1976 under the second phase of the new scheme. It is, therefore, not possible to determine how much of the difference in the results between 1974 and 1976 is due to season or treatment. In general, total yield was less, grasses particularly *Arrhenatherum* contributed less but legumes and other species relatively more in 1976 than in 1974. The 1976 analyses like 1974 showed more *Anthoxanthum, Festuca rubra* legumes and *Taraxacum* but less *Poa trivialis* on sub-plot *b* than on *c*. On the other hand, results for *Dactylis, Poa pratensis* and *Anthriscus* were in 1976 opposite to those in 1974.

The largest effects of increased rates of lime were on $11^1 b$, which received 25 t ha^{-1} of chalk and whose pH was only 4.2 at the outset, and on $11^2 b$, which received 15 t ha^{-1} of chalk and whose pH was 4.7. The increased amounts of lime on these sub-plots almost halved *Alopecurus* but increased *Arrhenatherum*, particularly on 11^1. *Holcus*, however, which had become plentiful in recent years, especially on 11^1, was markedly decreased. Small amounts of *Lathyrus* were found in samples from both *a* and *b* sub-plots of plots 11^1 and 11^2 in 1974. *Anthriscus* and *Heracleum* were increased by the increased rates of liming.

9L

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3. COMPARISON OF THE BOTANICAL COMPOSITION OF PLOTS 3, 7 AND 14 IN 1975 AND 1976

(Tables 42, 43, 44 and 45)

The present botanical composition of these plots has already been discussed when successional changes were presented and the very different weather conditions preceding the 1975 and 1976 harvests have also been emphasised.

There was nevertheless good agreement between the results for the two seasons especially for the major components on the plots. For example, on the unlimed half of Plot 3 (Unmanured), *Festuca rubra* contributed 32-33% in both seasons and *Agrostis* on the unlimed half of Plot 7 (PKNaMg) was 29 and 31% in 1975 and 1976 respectively. Also on the unlimed half of 14 (N_2*PKNaMg) *Arrhenatherum* and *Alopecurus* were co-dominant but on the limed half *Arrhenatherum* was dominant in both 1975 and 1976. The unlimed half of Plot 7 consisted of 30% *Arrhenatherum* in 1975 and although only partial analysis was done in 1976 (Table 44) about three-quarters of the grass fraction (40%) appeared to consist of *Arrhenatherum* in that year.

There were also some differences between seasons. The most significant of these was the increase in % other species on the limed half (L) of Plot 3 and the large increase in % legumes on the limed half of Plot 7 in 1976 compared with 1975. The increase in other species on 3L in 1976 was mainly at the expense of the grasses but the increase in legumes on 7L was accompanied by a decrease in other species so evidently the drought induced different reactions in different communities. Particular species e.g. *Hypochaeris* and *Leontodon* were much encouraged in 1976; *Dactylis* and *Lolium* also appeared more abundant than usual and *Arrhenatherum* was more plentiful on 14L in 1976 than in 1975.

DISCUSSION AND CONCLUSIONS

CHANGES WITH TIME

As pointed out in the Introduction the present analyses were initiated to quantify the changes in botanical composition on those sub-plots which had received new or increased rates of lime under the new liming scheme. The analyses were then extended to include plots with unchanged treatment to assess whether and how much they had changed since the previous hay analyses during 1948 and 1949. At the same time it became clear that a better appraisal of the present-day flora would be achieved by considering it not only in relation to changes in the immediate past but also in relation to the main changes on the plots throughout the duration of the experiment. The scope of the work was, therefore, widened from a presentation of the results of the 1973-1976 analyses to include also a review of past results. However, because of the large amount of accumulated data the results section dealt only with those changes which were deemed large enough or to have continued for long enough to be obviously 'significant'. It is likely that other changes have occurred especially in minor components which the method of analysis was not sensitive enough to detect. Plot yields have changed (usually decreased) slowly with time but except in the early (1862-77) and late (1973-76) analyses the amounts of species per unit area of land were not calculated; in view of the yield changes it is possible that over a period of time the changes in the amount of species might be somewhat greater or smaller than the percentage figures suggest. Although percentage composition can be compared throughout, because of the change

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