Rothamsted Report for 1936

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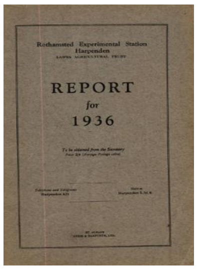

Grassland Investigations

Rothamsted Research

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REPORT FOR 1936

Certain of the Rothamsted investigations have been selected for detailed discussion in the present Report because of their bearing on immediate problems or because they have reached a stage where several years' work can be summarised. Present-day agriculture is becoming accustomed to rapid changes, and the technical adviser is confronted with new and pressing problems. He in his turn must rely on the agricultural research institutes for information and experimental results on which to base his advice. The increasing calls made on research institutes can only be answered with confidence if the results of careful and exact experiments are available. Thus, in a time of rapid change and of new problems, there is not less, but more need for steady and unhurried research work on the fundamental problems of agricultural science. The information from such experiments is of permanent value and can be easily translated to suit any particular economic and practical circumstances. Without it only a tentative opinion can be given ; in the present condition of agriculture, tentative recommendations are of little use to the farmer.

Nevertheless, there is often a danger that a long-range programme may become unnecessarily remote from practice, and practical conclusions may remain unnoticed because they have never been put into a form in which they can be used. The remedies are to keep the research programme under constant scrutiny, to follow-up immediately those results that are likely to have a practical bearing, and to maintain close touch with technical advisers and farmers.

The staff of Rothamsted endeavours to relate its research activities to current agricultural problems as closely as resources and available facilities will allow. Examples of this are the grassland investigations, and the study of how far crop yields are affected by cultivation, which are discussed below.

GRASSLAND INVESTIGATIONS

In the past few years farmers have taken much interest in the rotational grazing of grass, and in grass drying. Although some of the original enthusiasm has evaporated, there is little doubt that both methods will become established, perhaps in a modified form, in suitable parts of the country. Meanwhile, many important aspects of both new and old methods of grassland management need fuller investigation ; those dealing with soil, manuring and the composition of grass fall within the scope of the Rothamsted programme.

Work at Rothamsted on grassland problems began in 1856 when Lawes and Gilbert laid out a manurial experiment known as " Park Grass " on an old established meadow whose botanical composition was sensibly uniform. In the first few years of the experiment the first cut was mown for hay and the aftermath grazed by sheep, but since 1872 any aftermath has been mown. The Park Grass plots are of great historical interest for they supply a continually lengthening record of the effect of manures and seasons on hay yield and botanical composition. Marked changes in botanical analyses are not, however, confined to permanent grassland. They are also shown on newly established grass, and the botanical analyses may bear but little relation to the often elaborate seeds-mixtures sown a few years earlier.

The increasing interest in the control of weeds on arable land by chemical sprays raises the question whether neglected and weedy grassland could similarly be improved. Some experiments with ammonium thiocynate showed that its effect was uncertain except possibly for annual weeds in a dry summer, while granular cyanamide was not effective.

The manuring of grassland presents a different problem from arable crops owing to the competition between different species and the association of grasses and leguminous plants. Finnish studies have indicated that the roots of legumes exude nitrogenous compounds, to the benefit of grasses growing in the same soil. Dr. Thornton and Dr. Nicol have confirmed this work for lucerne and grass in sand cultures. They have also shown that the benefit of nodule bacteria to the host plant depends greatly on the strain of the organism. The clover on certain Welsh sheep pastures is associated with a "poor" strain; much more efficient strains have now been isolated which can successfully compete with the poor strain for nodule formation on the host plant.

The nitrogen cycle in grassland soils has been less studied than that for arable land. The Park Grass plots provide excellent material for studying the conditions in old established grassland, and Dr. Richardson has shown that there, and elsewhere, nitrate and ammonia have low equilibrium values, which are rapidly re-established after the addition of inorganic nitrogenous fertilisers. He also obtained strong evidence for the view that herbage takes up ammonia directly, and showed that the depressing effect of sulphate of ammonia on clovers in the field is probably due to the increased competition of the non-leguminous plants.

The striking improvement effected by phosphatic manures on poor grassland are not to be expected on medium quality land, and accurate measurement of the results is exceedingly difficult. However, Dr. Crowther has shown that if the yields of hay are supplemented by determinations of the amount of phosphate taken up in the crop, reliable and consistent results are obtained. The results have a direct bearing on the nutritive value of the crop, a subject which has also engaged the attention of Dr. Norman. He has examined the composition of rye grass (Western Wolths) cut as young grass throughout the growing season, and finds that the second growth is higher in structural cell-wall constituents such as cellulose and lignin and lower in carbohydrates such as fructosan than the first cut, when compared on a basis of equal protein contents. Rotation grazing and the use of dried grass as a food-stuff are both advocated in the belief that the nutritive value of young grass is secured over the greater part of the growing season; but Dr. Norman's results show that later cuts, although "young" in the sense of time, more nearly resemble the composition of the mature uncut herbage. Obviously other grasses must also be examined, and this work is in hand.

The points mentioned above are discussed in detail in Sections *a-g* that follow.

(*a*) BOTANICAL COMPOSITION OF MANURED MEADOWLAND.

Since the Grass Plots were laid down by Lawes and Gilbert in 1856 more than half the plots have received the original manurial treatment year by year until the present day. The treatment of the rest has been changed or modified at one time or another, but in no case more recently than 1905. The outstanding alteration in the original policy occured in 1903, when a four-yearly system of liming was instituted over one half of most of the plots, the remainder coming into the scheme in 1920. Complete botanical analyses were made at five year intervals from 1862-1877 and again in 1914 and 1919 by Dr. Brenchley and the results published in full ([1], [2]). Since then complete analyses have been made annually from certain of the plots with a view to obtaining more detailed information on various aspects of the response to treatment.

The general composition of the herbage with individual treatments became established early in the experiment. Unmanured plots carry many species, well distributed among grasses, leguminous and miscellaneous plants, with various species indicative of poverty, the yield of hay being low. Mineral plots also carry many species, of more luxuriant growth, with a large proportion of leguminous plants. With heavy nitrogen applications the number is greatly reduced, but the behaviour of the groups of plants depends upon the form of the nitrogen application. With ammonium sulphate leguminous and miscellaneous plants have practically disappeared, whereas with heavy dressings of nitrate of soda some weeds, as dandelions, are abundant, and with light dressings, without any addition of minerals, a very weedy herbage is produced, containing a fair proportion of leguminous plants.

Within the main outlines, however, the botanical composition of the herbage varies greatly from year to year. With complete fertilisers including nitrogen and minerals the relative proportions of the three main groups of species, i.e., grasses, leguminous and miscellaneous plants, are not usually much affected by season, though the individual species do vary, but with one-sided fertilisers and on unmanured areas wide fluctuations occur in the percentage of these groups. No correlation has been traced between the annual variations in the yield and the botanical composition of the herbage, except for some suggestion of association between high yield and high percentage of leguminous plants with long-continued mineral manuring.

The variations of individual species occur on all plots. They may be caused by direct or indirect response to season and are much influenced by the type of manuring. It is often difficult to determine whether a marked increase or decrease of a species in any year is due to climatic conditions being beneficial or detrimental to that particular species. It may be that the real effect is on other constituents of the herbage which change so much that the proportion of the species under consideration is radically affected (cf. *Alopecurus* in 1922). In some cases, especially with organic fertilisers, the

(1) Lawes, J. B., Gilbert, J. H. and Masters, M. T. (1882.)—" Results of experiments on the mixed herbage of permanent meadow." Part II. " The botanical results." Phil. Trans. Part IV. pp. 1181-1413.
(2) Brenchley, W. E. (1924.)—" Manuring of grass land for hay." Longmans, Green & Co. Rothamsted Monographs. pp. 144.

main groups and also certain species (as of *Alopecurus, Arrhenatherum, Dactylis*) show a tendency to rhythmic changes with season, rising and falling over a period of years. In other cases the fluctuations are more abrupt and irregular, sometimes being exaggerated in the presence of lime.

The response to liming is most marked on liberally manured plots, particularly those receiving sulphate of ammonia. Even in the winter these limed areas stand out clearly, whereas much less differentiation is seen on poorly manured plots and on those receiving nitrate of soda. With ammonium sulphate and minerals liming has completely changed the balance of the botanical composition within the group of grasses, though it has not re-introduced weeds and leguminous plants. Individual species usually respond to lime at once, showing a change of proportion at the first succeeding cut, but under certain soil conditions a delay may occur until a second dressing has been given. It would appear that the maximum effect of liming is reached within a few years from the first application, after which fluctuations with season may again become more obvious. ([1], [2]).

The heavy frost of the winter 1928-1929 and the spring drought in 1929 were responsible for killing the herbage on the unlimed halves of plots receiving ammonium salts and minerals, that on the limed areas not being adversely affected. Prior to this large percentages of *Anthoxantham oderatum, Arrhenatherum avenaceum, Festuca ovina, Alopecurus pratensis,* as well as *Holcus lanatus* had been present on one or other of the plots, but when recovery began after the original herbage had been wiped out *Holcus lanatus* usurped the field almost to the exclusion of everything else. On the unlimed halves of plots receiving ammonium sulphate and complete minerals, 100 per cent. *Holcus* is still present, but on the others, where potash is withheld, the return of other species is proceeding very gradually.

Since the publication of the analyses and results to 1934 ([3]) a five year cycle of analyses has been begun on specified plots, to obtain information as to the correlation between seasonal effects and potash manuring. The question of the effect of shading is also being investigated, as there are indications that certain species may be greatly increased or decreased by shading, whereas the proportion of other species may not be affected. Sufficient figures are not yet available, however, to allow of any comparisons being made on either point.

(*b*) Seeds mixtures and botanical composition of resulting herbage

Sawyer's field was laid down to grass in the spring of 1928, six different mixtures being sown. Up to and including 1935 it was regularly grazed, being cut for hay for the first time in 1936.

(1) Brenchley, W. E. (1925.)—" The effect of light and heavy dressings of lime on grassland." J. Min. Agric. XXXII. pp. 504-12.
(2) Brenchley, W. E. (1930.)—" The varying effect of lime on grassland with different schemes of manuring." J. Min. Agric. XXXVII. pp. 663-73.
(3) Brenchley, W. E. (1935.)—" The influence of season and of the application of lime on the botanical composition of grassland herbage." Ann. Appl. Biol., XXII, pp. 183-207, also Ann. Rept., 1934, pp. 142-159.

Botanical analyses were started by Miss Warington in 1929. For the first two years an attempt was made to estimate the relative proportion of the individual species on each plot, but as the sward became closer it was not possible to do this with any degree of accuracy, and it seemed preferable to determine the percentage of total grasses, leguminous species, weeds and bare space only on the field, and to supplement this data by a detailed botanical analysis of every species on small areas allowed to grow for hay.

Ten of the general analyses were made per plot every spring and autumn, areas of 1 foot square being used, while hay samples were taken in duplicate from 2 foot square areas, protected from the grazing animals by covers which were removed immediately after sampling. Selection of the areas for both types of analysis was made at random, except that tracks to water troughs or gates were avoided. Establishment was slow owing to the severe winter of 1928 and the drought in the following spring, but growth rapidly improved, and the bare space which in 1929 amounted to about 30 per cent. was reduced to 5-10 per cent. on most plots in the following year.

In spite of the great variety of the mixtures sown (Table I), the differences between the composition of the plots are comparatively slight, and as would be expected the levelling up has become more pronounced in the course of time. On the whole, the seasonal effects have been the same throughout the field, whether this applies to the normal spring and autumn fluctuations, or to unusual features such as the drought in 1933.

TABLE I

Composition of Mixtures Sown, lb. per acre 1928.

	I	IV	V	VI	VII	VIII
Italian Rye	—	—	—	4	4	4
Perennial Rye	10	16	30	—	—	5
Cocksfoot	8	10	10	10	6	5
Timothy	2	4	—	2	4	2
Tall Fescue	—	—	—	10	—	—
Meadow Fescue	2	—	—	—	10	5
Meadow Foxtail ..	—	—	—	—	3	5
Rough Stalked Meadow	2	0.5	—	1	2	1
Early Red Clover ..	1	—	—	—	1	—
Late Red Clover ..	2	4	—	3	3	4
Alsike	—	—	—	1	—	—
Wild White Clover ..	1	1	1	1	1	1
Trefoil	—	—	—	—	2	—
Chicory	2	—	—	2	—	—

In 1931 the percentage of bare space was reduced to below 10 per cent. on all plots, so this may be regarded as the point at which the sward had become thoroughly well established. At this time grasses and clovers were of approximately equal importance on all plots (approximately 40-50 per cent. of each throughout). Clover maintained this position until 1933 when it was almost completely killed by the drought. Its place was to a large extent

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taken by grass, although the percentage of bare space also rose considerably, in some cases to 20 per cent. Since 1934, a gradual return of clover has occurred, the re-establishment being rather less rapid on plots sown with mixtures I and VI than in the other cases, but although clover now comprises approximately 10-20 per cent. of the herbage on all plots, (Table II), it has nowhere regained its former importance. Except after very hot summers, there seems a tendency for the percentage of clover to be higher in the autumn than in the spring. This explains the rather lower figures for clover from the hay samples taken in June, (Table III), compared with the direct estimations made on the field in the autumn of the same year.

TABLE II

Percentage Composition of Herbage, 1936. (*September*)
Direct estimation on field. 1 *ft. sq. area. Mean of* 10 *samples.*

Mixture	I	IV	V	VI	VII	VIII
Grasses	81.3	79.3	76.7	90.2	83.7	80.9
Clovers	18.1	18.6	19.0	9.6	14.2	17.7
Weeds	0.4	0.05	0.4	—	0.3	0.3
Bare	0.2	2.05	3.9	0.2	1.8	1.1

TABLE III

Percentage Composition of Hay. 1936. (*June*)
Estimation from 2 *ft. sq. area. Mean of* 2 *samples*

Mixture	I	IV	V	VI	VII	VIII
Italian Rye	—	—	—	65.7	53.2	43.8*
Perennial Rye	67.5	51.9	54.6	—	—	
Cocksfoot	7.9	13.5	8.9	15.4	18.6	24.9
Timothy	4.4	9.8	2.6	6.7	4.7	6.8
Fescue (flowering shoots only)	—	—	—	0.2	—	0.1
Rough Stalked Meadow	11.1	6.4	15.9	7.7	14.5	16.0
Grasses (various) ..	0.2	—	1.8	0.2	—	0.7
Red Clover	—	—	—	—	—	—
Wild White Clover ..	8.7	16.0	15.7	4.1	8.8	7.5
Weeds	0.2	2.4	0.5	—	0.2	0.2

* Accurate separation of the two species was not possible but on the basis of the flowering shoots by far the greater proportion was perennial rye.

Any differences in clover content between the plots at the present time cannot be attributed to differences in the amount of seed sown, as wild white clover is the only leguminous species that now occurs and this was sown at a uniform rate over the whole field. Red clover was included in all mixtures except V, two plots receiving alsike or trefoil in addition. Red clover achieved some importance (10-20 per cent.) on two plots only and it may be significant that both these were sown with the larger amounts of the late flowering variety. All forms of red clover, the alsike and trefoil were short-lived, nothing more than traces being found after 1932.

The proportion of the field covered by graminaceous species has steadily increased, and now amounts to about 82 per cent. of the herbage on the average. Rye grass has been, and still is, the most important species irrespective of the amount or variety sown. Mixtures VI and VII contained the Italian variety only ; mixture VIII a mixture of the Italian and perennial varieties ; while the remainder supplied perennial rye grass. The Italian rye was rather slower in achieving its dominant position than the perennial, doubtless owing to the smaller quantity of seed sown. On the other hand, on the plot receiving a mixture containing a specially large quantity of perennial rye, this species has shown no particular rapidity in assuming dominance. The persistence of the Italian rye is notable and in the spring the strips sown with it stand out conspicuously owing to its earliness in coming into growth.

At the outset cocksfoot was an important species comprising 20-30 per cent. of the sward. Reduction has since occurred on all plots to a varying degree and at present this species covers an area ranging from 8-25 per cent. No correlation with the quantity sown is found. Fescue was an important constituent of three mixtures only and though it temporarily amounted to 11-22 per cent. on these plots, it still occurs only where sown and since 1933 has been almost negligible. Rough stalked meadow grass was slow in becoming established but has noticeably increased in quantity since 1931. There seems little correlation with the quantity sown and it now comprises approximately 16 per cent. of the herbage on a plot the mixture for which contained none at all. Meadow foxtail was sown in small quantities on two plots, but failed to become established. Timothy has proved a persistent but unimportant species, the rate of seeding having little bearing on the quantity found. Chicory was short lived surviving for barely 2 years. Weeds have on the whole been negligible, though thistle began to be noticeable in 1936. Cutting for hay in this season may help to discourage this species.

Summarising the general position, the outstanding features seem to be, (1) rye grass sown as the chief constituent of a mixture readily assumes and retains dominance, the Italian variety proving unexpectedly persistent ; (2) cocksfoot rapidly gains a footing, regardless of the proportion sown ; (3) rough stalked meadow grass is slow in becoming established, but is able to spread itself to a considerable extent ; (4) wild white clover is the only leguminous species that has proved persistent, the quantity in which it occurs being clearly determined by seasonal conditions, of which rainfall is the chief factor. It shows great powers of re-establishment after almost complete extinction.

All the known methods of grass analysis are open to some form of criticism, and those adopted in the present case have been used in full recognition of their shortcomings, value being attached to them principally in view of their continuity over a period of years. Accurate estimations of the relative proportion of individual species is impossible after the sward has become established, species such as rye grass and fescue being hard to distinguish when in a closely grazed condition, and it is unfortunate that it is these same species that offer difficulty in hay analyses. The time factor is important in field work of this nature and although a large number of repli-

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cates is desirable, some accuracy is lost if the estimations are not made within a few days of each other at times of rapid growth. The cutting of turves for investigation in the laboratory is of course ruled out when plots are small and the experiment of long duration.

(c) Experiments on weed control by sprays

In the course of an experiment on the value of thiocyanates as weed killers attention was directed to a piece of neglected grassland which was so covered with weeds that very little grass could be seen anywhere, though it existed under the shadow of the weed leaves. Marked plots were sprayed with 1, 2½ and 5 per cent. solutions of ammonium thiocyanate, operations being carried out on June 25th, 1935, at 11 a.m. in brilliant sunshine, but at 4 p.m. there was a storm with very heavy rain, followed by much rain during the night. In spite of this definite results from spraying were obtained.

Calamintha clinopodium was the most abundant species, covering the whole area quite densely. Twenty-four hours after spraying the 1 per cent. plot looked scorched, the 2½ per cent. was badly hit and was turning brown, while the 5 per cent. plot was very badly damaged and was dark brown. The most susceptible plants at this stage were species of *Cirsium*, Bramble, *Nepeta* and *Potentilla*, the degree of damage increasing with the concentration. Many of these plants were already killed, but the majority of other species were damaged to some extent, at least by the 2½ per cent. and 5 per cent. solutions.

As time went on the varying effect of the different sprays became more and more marked. The unsprayed control plot remained a mass of weeds, which flowered and fruited freely, and by October could still be described as " weeds, with some grass."

With 1 per cent. thiocyanate nothing seemed to be entirely killed, though most species were considerably checked, especially as regards flowering. By October the weed growth was fairly good but shorter than that on the control plot, and more grass was visible, while very few weed species had reached the fruiting stage, *Calamintha* having only recovered sufficiently to be in flower.

The 2½ per cent. thiocyanate proved to be quite reasonably effective in controlling weeds. *Calamintha* was entirely prevented from flowering, and only a very little *Cirsium* and *Agrimonia* came into bud. The grass, however, was much improved and showed stronger growth and a better colour than that on either the control or 1 per cent. sprayed plot.

The results of the 5 per cent. spray were outstanding, for by October the plot could be described as " grass with weeds." A general killing-out of many species had occurred, and most of those that were left were either barren or very sparingly in flower. Thistles failed to flower, *Rumex* made no recovery from the initial check, and *Calamintha* showed very little flower. The great feature of this plot was the large proportion of grass at the last inspection. The impression was given that a second spraying in August or September with 2½ per cent. or 5 per cent. solution might have eradicated *Calamintha* more or less completely.

In 1936 the original plots were re-sprayed and a fresh series marked out to compare the effects of early and late spraying, alone and together, with the same concentrations as before, and also with a 10 per cent. solution.

The early spraying was done on March 18th, when the original 5 per cent. plot still showed the beneficial effect of the 1935 treatment. The other areas were selected with as uniform a weed cover as possible and in addition a dense patch of bramble was treated. At this date very little fresh growth had been made, and dead leaves and flowering stalks predominated. Spraying at this early stage proved to be of little value except for killing moss, as most of the weeds pushed up their new leaves later on and were not damaged.

The second spraying, on June 17th, was more effective and much of the weed was killed, especially with the higher concentrations. The very wet weather during the summer, however, undid the work of the spray, as new growth was encouraged and most of the plots were ultimately as weedy as before any spraying was done. With 10 per cent. solution applied late, however, some weed reduction persisted in spite of the wet season, and *Calamintha clinopodium* and thistles were severely affected and did not flower. A certain amount of benefit occurred from the nitrogen supplied by the thiocyanate,as with the heavier sprayings the herbage was much deeper green than on the control plots.

Comparative tests were made with dressings of granular cyanamide, but neither early nor late applications were effective in reducing the weed cover, though the nitrogen effect was again distinctly marked.

The attempt to reduce bramble by early spraying with a 10 per cent. solution at first looked promising, as the plants were very badly damaged and for some time remained much behind the controls. Later on, however, bramble received the same encouragement from the wet summer as the herbaceous weeds, and the only persistent reduction was where early and late spraying had been done on the same area.

The general outcome of the two years' experiment is that thiocyanate is an uncertain agent for weed reduction on grassland. It has a good temporary effect, and in a dry summer might prove very useful, as it is for the eradication of annual weeds among certain crops. It seems, however, that the underground parts of perennial weeds are not seriously effected by the thiocyanate, and weather conditions which encourage lush growth enable damaged plants to again start into growth and eventually to make very good recovery.

(*d*). Legume-grass associations

The ecology of " grass-land " presents the problem of growing legumes in association with other plants in its most complicated form. Factors that benefit legumes when grown alone may not be beneficial to legumes growing in competition with other crops. The effect of mineral nitrogen is an important instance of this. When a legume is grown alone, mineral nitrogen supplied to it tends to replace nitrogen that would otherwise be supplied by the

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nodules, whose development is hindered by the nitrogen manuring. (Thornton and Nicol, **1936**, J. Agric. Sci., **26**, p. **173**). But the legume may grow as well from whichever source its nitrogen is derived. The manuring is merely wasteful but not actually harmful. But where a legume is grown in association with grasses, a supply of mineral nitrogen is actually harmful to its growth, since it stimulates the grass to excessive competition with the legume. This was clearly shown in a pot experiment with lucerne and grass supplied with sodium nitrate, in which the growth and nitrogen content of the lucerne was inversely related to the dose of nitrate applied (Thornton and Nicol, **1934**, J. Agric. Sci., **24**, p. **269**). In grassland, therefore, it is especially necessary to rely upon the activity of the nodule bacteria in supplying nitrogen to legumes, since nitrogen compounds cannot safely be supplied to them without stimulating grass competition. Nodule development can be stimulated by phosphates which increase the infection of legume roots by the nodule bacteria (Thornton and Gangulee, Proc. Roy. Soc., **1926**, B, **99**, p. **427**). The well-known effect of phosphate in stimulating legume growth in pastures is probably due to this fact.

It is not merely necessary to obtain an adequate development of nodules however : these must also fix nitrogen actively. Recent work has shown that strains of nodule bacteria vary greatly in the benefit which they confer on their host plant. This is especially the case with those that infect clover, some strains of which do not supply detectable amounts of nitrogen to the plant, while others are highly efficient as nitrogen fixers. Some of the former inefficient strains have been isolated from clover that was growing in certain Welsh sheep pastures. These " poor " strains present a problem of considerable agricultural importance, which is rendered more difficult because they have been found to compete for nodule formation with other and more useful strains. The cause of this competition between good and poor strains of clover nodule bacteria is now under investigation in the Bacteriology Department. It has been found that dominance in strain competition is not correlated with the efficiency or otherwise of the strain, and two highly efficient strains have been isolated that can compete effectively for nodule formation when supplied to the clover plant together with a " poor " strain. They should be useful for inoculating clover to be sown in soil containing a population of a " poor " strain of the bacteria.

In grassland the legumes are beneficial not only by virtue of their high protein content, but also because some of the combined nitrogen resulting from nodule activity is handed on to the grass. Until recently the beneficial effects of legumes on other crops was studied principally in rotations and attributed to the residual value of nitrogen compounds released when the legume roots decayed. Recent work, carried on principally in Finland, has shown that considerable amounts of combined nitrogen are secreted into the root surroundings by young and actively-growing legumes. Our own work showed that when lucerne was grown in sand culture with grass, the latter obtained appreciable amounts of combined nitrogen from the lucerne within 3 months of sowing. (Thornton and Nicol, 1934, J. Agric. Sci., **24**, p. 540). This nitrogen excretion by legumes suggests practical problems concerning the conditions favourable to it, and the associated plants best suited to benefit thereby.

(*e*). Nitrogen in grassland soils

Most of our knowledge of the nitrogen cycle in soils is derived from arable land, and, until recently, there was very little information on grassland soils. It was commonly assumed without evidence that in grassland nitrogen compounds in the soil organic matter or in added manures were unavailable to plants until they had been converted into nitrates. In systematic soil investigations on Park Grass plots and some other fields over several years, Dr. H. L. Richardson found that both nitrate and ammonia contents were very low, of the order of a few mgs. nitrogen per kg. of soil. In contrast with arable land the ammonia was always higher than the nitrate. Fluctuations throughout the season were very small, except on a very acid soil on which the herbage was seriously damaged by frost and drought. Even when nitrogenous fertilisers were added the low equilibrium values were rapidly re-established, one half of the added inorganic nitrogen disappearing within a few days in spring or within a week or so in winter. Nitrogen added as sulphate of ammonia was taken up by the plant roots directly without previous nitrification. By incubating soil samples under standard conditions and measuring the ammonia and nitrate formed, it was found that the mineralisable nitrogen followed a seasonal rhythm, rising in late autumn and falling in late spring and summer. This reflects the changes in the more active parts of the soil organic matter as residues of herbage are introduced into the soil in autumn and oxidised away when the temperature rises in spring. The nitrifying power of the soils was very low on the most acid plots and on one or two others. Since the nitrate content of field soils was below the ammonia content, even for soils which nitrified rapidly in the laboratory, it was inferred that most of the nitrogen made available in the ordinary course of the nitrogen cycle in the field was taken up by the herbage as ammonia.

Under Rothamsted conditions old grassland attains a nitrogen content of about 0.3 per cent. as compared with 0.15 per cent. in arable land. From old grassland of known age it would appear that about 25 years are required for the nitrogen content to rise half-way to the maximum when arable land is laid down to grass.

In annual experiments on the use of nitrogenous fertilisers on grassland it was found that winter applications were less effective than spring ones, and that calcium cyanamide, with or without dicyanodiamide, was less effective than sulphate of ammonia in winter and about equally good in spring. Under repeated mowing the added nitrogen disappeared from the soil very rapidly and the response in herbage was exhausted in one or two cuts. In these early cuts the recovery of added nitrogen did not exceed 40 per cent.; in the later cuts there was a marked depression in clovers. Pot experiments showed that clovers could grow well in the presence of repeated very heavy dressings of sulphate of ammonia equivalent altogether to no less than 24 tons per acre, and the depression in the field must be ascribed to competition rather than to direct toxicity.

(*f*). Phosphatic fertilisers on grassland

The series of investigations continued since 1920 on behalf of the Ministry of Agriculture's Permanent Committee on Basic Slag provide useful illustrations of the difficulties of obtaining quantitative comparisons of various methods of grassland improvement. On poor land basic slag or other treatments may effect such revolutionary changes in the amount and quality of the herbage that a trial on a single plot or field carries absolute conviction and no elaborate experimentation is called for. On land of medium quality such spectacular results are not to be expected and attempts to compare alternative manures or to find the best rates of dressing merely by inspection of grazed fields have often given ambiguous or even misleading results. It is obviously a matter of supreme difficulty to conduct quantitative experiments on the manuring of pastures.

In 1920 it became necessary to test a number of kinds of basic slag in order to ascertain whether or not those of lower solubility in the conventional reagent—2 per cent. citric acid—were in fact less effective than the older and better-known types of high solubility. The first series of experiments was made on one-acre plots at Rothamsted which were grazed with equal numbers of sheep. The manures were given in 1920 and again in 1924 and the experiment continued until 1928. The live-weight increases of the sheep varied widely from year to year (e.g., from 80 lb. to 218 lb. per acre). In some seasons the herbage grew more rapidly than the sheep could graze it with the result that both grass and sheep suffered later in the season. Only one of the five phosphatic fertilisers tested caused any appreciable increase in the live weights. In similar experiments conducted from 1925 to 1928 in Somerset and Leicestershire the results were also small and irregular. These apparently direct experiments failed to give results commensurate with the trouble entailed. The conditions arbitrarily imposed to ensure a formal uniformity destroyed the necessary balance between growth and grazing, and, even if these conditions had been altered, the results would have remained uncertain in the absence of any estimate of the irregularities in the soils and the animals.

In order to adopt modern methods of field experimentation the next series were restricted to land set up annually for hay. The first experiments in 1926-9 showed that on land of moderate fertility it was possible in this way to distinguish between different types of slag, especially if the hays were analysed to determine the uptake of the phosphoric acid added in the slags. From the summary in the following table it will be noticed that about 15 per cent. of the phosphoric acid in the most soluble slag was removed in the hay, as compared with 5 or 8 per cent. from the least soluble slag.

Mean yields and recovery of phosphoric acid in two hay trials, 1926 *to* 1929

	Percentage citric acid solubility of slag	Mean yield of hay cwt. per acre		Percentage recovery of added P_2O_5	
		Brooke Norfolk	Enmore Somerset	Brooke	Enmore
Slag H ..	87	31.0	24.2	15	14
Slag M ..	61	27.9	25.4	11	14
Slag L ..	37	25.5	23.3	5	8
No phosphate	—	22.6	20.7	—	—
Standard error	—	0.86	1.13	—	—

A wider series of hay experiments in 5 by 5 Latin Squares was carried out from 1930 to 1933 on high- and low-soluble slags, superphosphate and mineral phosphate.

Mean yields and phosphoric acid recoveries in four-year hay experiments on High-soluble slag H, Low-soluble slag L, Mineral phosphate M, and Superphosphate S.
1930-33 (*Northallerton* 1931-34)

	Mean yield of dry hay on plots without phosphate	Relative mean yields (Without phosphate =100)				Percentage recovery of added phosphoric acid			
		L	M	H	S	L	M	H	S
Neutral Soils	*cwt. per acre*								
Braintree, Essex ..	19.4	109	105	132	128	3	3	17	17
Badminton, Glos. ..	32.4	99	98	103	107	2	4	13	16
Acid Soils									
Cockle Park, N'umberl'd	6.2	134	194	171	181	3	10	7	8
N'allerton, Yorks.	15.7	121	138	142	142	6	18	20	23
Chesterfield, Derby	31.3	109	114	113	120	6	13	13	15
Lydbury, Salop.	34.3	102	105	103	101	10	19	14	18

The series covered a wide range of conditions of soil fertility as may be seen from the fact that the average yields over four years varied from 6 cwt. of dry hay per acre on the poor soil at Cockle Park to over 30 cwt. per acre at three of the centres. As was to be expected the responses to phosphate were relatively small at the centres which gave high yields without manure. High-soluble slag and superphosphate gave similar results throughout ; superphosphate gave the greater effect in the first season but the high-soluble slag caught up in total yield over four seasons. Low-soluble slag was far inferior at all responsive centres. Mineral phosphate was as effective as the high-soluble slag and superphosphate on the acid soils but it was even less effective than the low-soluble slag on the two neutral soils. The figures for the percentage recovery of the added phosphoric acid showed a much more consistent story than the

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yields. Except from the very poor Cockle Park soil the recovery of phosphoric acid from the high-soluble slag and superphosphate fell within the range 13 per cent. to 23 per cent. and at no centre was there any appreciable difference between the two materials. On the four acid soils the recoveries from mineral phosphate were similar to those from the two more soluble fertilisers and far higher than those from low-soluble slag. These experiments show that when hay trials are supplemented by chemical analyses to determine the actual uptake of the added nutrient, they are capable of giving reliable and consistent data, even though the yield results may show only comparatively small effects of treatment.

In the Northallerton experiment the hay samples for each plot were analysed separately each year and it was therefore possible to establish highly significant improvements in the composition and feeding value of the hay as well as in the weight of hay.

Northallerton Hay Experiment 1931-4

	Without Phosphate	Low-soluble slag	Gafsa Mineral Phosphate	High-soluble slag	Super-phosphate	Standard Error
Yield of dry Hay, cwt. per acre						
1931	24.3	29.5	33.6	36.4	37.8	0.79
1932	12.8	15.2	18.6	19.3	18.7	0.43
1933	14.6	18.2	21.0	21.3	19.9	0.44
1934	9.5	12.0	14.0	14.3	13.2	0.16
Nitrogen as percentage of dry Hay						
1931	1.32	1.36	1.55	1.58	1.59	0.032
1932	1.56	1.68	1.82	1.81	1.89	0.063
1933	1.28	1.40	1.51	1.45	1.49	0.028
1934	1.24	1.32	1.34	1.36	1.36	0.022
Phosphoric acid as percentage of dry Hay						
1931	0.28	0.33	0.48	0.51	0.56	0.0009
1932	0.30	0.34	0.43	0.43	0.45	0.012
1933	0.24	0.26	0.32	0.32	0.33	0.007
1934	0.24	0.26	0.30	0.31	0.32	0.005
Calcium oxide as percentage of dry Hay						
1931	1.01	1.16	1.32	1.37	1.38	—
1932	1.06	1.23	1.45	1.29	1.41	—
1933	1.20	1.28	1.32	1.24	1.32	—

In order to make comparisons on young grass, experiments were carried out by repeated mowings at Dartington Hall, Devon, (by Mr. J. B. E. Patterson), and at Much Hadham, Herts., on acid and neutral soils respectively. In the later experiment there was one 5 by 5 Latin Square with plots mown five times annually, and five similar squares which were grazed throughout the year except when each one in turn was fenced off for three to four weeks and then mown. There were clear effects on yield and composition of the herbage in the early years of each experiment. The results are summarised concisely below as the percentage recovery each year of the added phosphoric acid. It will be seen that they are closely similar tothose for the earlier series of experiments on hay. Superphosphate gave the highest recovery in the first year and high-soluble slag the highest in the second year. Mineral phosphate was as effective as the two soluble fertilisers on the acid soil and comparatively ineffective on the neutral soil. Low-soluble slag was much inferior to high-soluble slag as a source of phosphoric acid.

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Percentage recovery of added phosphoric acid in repeatedly mown grass

	Low-Soluble Slag	Gafsa Mineral Phosphate	High-Soluble Slag	Superphosphate
Dartington Hall (acid soil)				
1930	1.1	4.3	7.6	10.8
1931	—1.4	12.0	12.4	9.6
1932	3.3	8.6	7.6	8.1
1933	3.0	4.2	3.7	3.3
Total	6.0	29.1	31.3	31.8
Much Hadham (neutral soil)				
Plots without grazing				
1931	4.6	2.5	14.5	16.6
1932	3.1	3.3	12.7	9.2
1933	1.3	1.8	6.6	3.5
1934	—0.4	0.2	2.7	0.9
1935	0.3	0.6	3.2	0.7
Total	8.3	8.4	39.7	30.9
Plots grazed with single mowing				
1931	5.4	4.0	13.6	20.4
1932	1.0	2.3	9.5	7.6
1933	0.0	2.4	3.7	3.0
1934	1.0	0.3	2.1	1.9
1935	0.3	0.9	0.8	1.4
Total	7.7	9.9	29.7	34.3

During the last few years certain steel-works have succeeded in producing a new class of medium-soluble slags in place of low-soluble slags and it became necessary to ascertain whether these new materials were more effective as fertilisers. The main field experiments were made on swedes in Scotland and are still in progress, but mention may be made here of a series of experiments conducted at Rothamsted on perennial rye-grass grown in pots in an artificial sand-bentonite mixture.

Percentage recovery of added phosphoric acid from basic slags in pot culture experiments on perennial rye-grass 1934-5

Percentage citric acid solubility of slag	23	24	30	42	44	53	61	66	89	93	96
mgs. P_2O_5 in crop per pot for											
250 mgs. total P_2O_5 added ..	64	59	66	87	105	106	128	135	160	174	179
500 mgs. total P_2O_5 added ..	92	95	119	156	159	189	211	229	286	292	303

Over a wide range of slags in single and double dressings the percentage recovery of the phosphoric acid was almost a constant fraction of the percentage citric acid solubility of the phosphoric acid in the slags. Under these highly simplified conditions the conventional citric acid method thus serves as a reasonably satisfactory measure of the availability of the phosphoric acid in basic slags. It will be noted too that these results are in harmony with those of all the replicated field experiments on grassland already discussed.

A new attempt to make a reliable comparison of slags on poor grazing land was commenced in 1936 by Professor Hanley in Northumberland. He used single plots of 5 acres for each slag and controlled the grazing of each plot independently. The improvements are to be measured by the progressive changes in the amount and composition of the herbage obtained on a series of randomly selected sample areas which will be fenced off at intervals. In addition comparisons are made on blocks of microplots without controlled grazing.

(*g*). THE COMPOSITION OF RYEGRASS

The experiments on the composition of Western Wolths ryegrass have been extended to include the examination of weekly cuts during the whole of the period of active growth, and second cuts from the same plots later in the season. As maturity was approached there was a progressive fall in the contents of protein and ash as expected, and a comparatively rapid rise in cellulose. The hemi-celluloses, as far as could be judged, increased steadily, while the lignin, initially quite low, nearly doubled, without giving any indication of a " lignification " period. Perhaps the most interesting feature, however, was the change in the amount of water-soluble fructosan, which, as reported previously, is a major constituent in young grass. This increased to a maximum of nearly one third the dry weight of the grass about the time of full emergence of the head, thereafter falling rapidly till in very old grass almost none was found.

The production of such a large amount of fructosan by ryegrass raises various physiological questions. A study of the distribution of this polysaccharide within the plant revealed that the stem is the chief place of storage, the first internode above ground level containing as much as **43** per cent. at the time of peak content. When maturity is reached no increase in total dry weight of the plant occurs although there is subsequently a steady rise in the proportions of the cell-wall constituents and particularly of cellulose. Since a concurrent fall in the fructosan was observed, there is a strong possibility that much of the temporarily stored fructosan is transformed later into structural material. The time of maximum yield of fructosan per acre does not quite coincide with the peak in percentage content, but follows about two weeks later, then amounting to as much as 3½ cwt. per acre. Should a market for fructose arise, ryegrass would be a potential source to be considered.

The second growth of grass differed considerably from the first growth in containing less fructosan, and being distinctly higher in structural cell-wall constituents, such as cellulose and lignin, when compared on a basis of approximately equal protein contents, thus suggesting that the second growth is more fibrous. It seems likely that in assessing the nutritive value of grass, sufficient attention has not been directed to the carbohydrate constituents. Fructosan should be very readily available, and utilised more completely than partially lignified cellulose. If the apparent differences in composition between the first and second growth of ryegrass are confirmed in other grasses, certain aspects of the policy of drying frequent cuts throughout the season may have to be reconsidered.