"THE INFLUENCE OF THE LIME STATUS OF THE SOIL UPON GRAMINEAE"

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C O N T E N T S

INTRODUCTION

GROWTH and DECLINE of LIMING PRACTICES

Since the very earliest days of husbandry it has been observed that some soils more than others, favour the growth of certain plants. The more readily a soil supported plants of value to man - either directly as human food or indirectly as forage for his domestic animals - the better he reckoned that soil to be. Thus we get the beginnings of the differentiation of soils according to whether they yield readily what man requires or only supply his needs sparingly or not at all.

It early became apparent to the primitive agriculturist that even good soils did not always yield consistently but gave returns more or less depending on the thoroughness with which the land was tilled, and as early cultivations were performed by hand the term "manure" came to be practically synonomous with "tillage". In this is seen the first recognition of the importance of soil "structure". Undoubtedly early cultivators would quickly appreciate the differences in soils due to the differences in texture. The cohesion of the particles and the retentiveness of moisture of very fine textured soils as against the greater friability and dryness of those of coarse texture are quickly made manifest to the worker, in the greater and less efforts required to produce a desirable "tilth". To this day the practical man differentiates soils as "heavy" or "light", having in mind the cultivations required. Measurements in units of weight per unit volume of course reverse the terms.

But while texture is an inherent and unalterable characteristic of a soil, depending on the average size of the particles, structure, which depends on the arrangement or grouping of the particles, is not. It may be improved or impaired very materially by judicious or injudicious treatment. The art of tillage - the performing of the correct operation, to the best extent, in the most advantageous season and weather for the particular type of soil - could only be acquired by husbandmen as the result of long generations of experience and the handing down of the accumulated knowledge. Many practices thus became traditional and continued without question or alteration to modern times. The majority of men deriving their livelihood from the land have in most ages lived too close on the margin of subsistence to take the risk attendant on innovations.

It has remained to modern science to question the validity of ancient beliefs and to probe for the principles on which the practices rest. Indeed, science is so young and agriculture so old that much of the investigation conducted of late years in so far as it has been concerned with agriculture has, of necessity, been directed to the explaining and approving or condemning of processes and beliefs of long standing. It is remarkable how well many of these survive the most critical examination.

Even though cultivations are carried out to the best of present-day man's ability, aided by the rapidly expanding knowledge of soil physics and the best available implements, the returns are very definitely limited if no additional treatment is accorded to the soil. Thus on the Broadbalk field at Rothamsted (38) over a period of 72 years when wheat was grown continuously without manure the average yield per acre was only 11.7 Bushels, whereas, the average yield for Great Britain (1) for the ten year period 1920/29 was 32.2 Bushels.

The early attempts at crop growing consisted in clearing a piece of land of the wild grasses and other vegetation and sowing the seeds in the upturned soil. Where the people were other than purely nomadic there was the natural tendency to use the same piece of land again and again owing to the greater ease in obtaining a seed-bed after the initial loosening of the surface. But the lesson (demonstrated in figures by Rothamsted to the present generation) was soon learned that this procedure quickly led to a diminution of productivity and the "wild field-grass" system of husbandry was adopted. New areas of grass were cultivated for grain and as the yield diminished they were allowed to revert again to native vegetation. Ernle (14) says, "Such a practice may belong to some portions of the Celtic race, or to nomadic stages of civilisation."

It is unknown when man first realised that more was required than mere cultivation and commenced applying substances to the soil to increase its productivity. Probably he was first impressed by the greater luxuriance of vegetation where cattle droppings were scattered; and he would observe that soil was more easily dug or ploughed in chalky districts than on clay areas. In any case, the use of chalk or lime as an ameliorative on soils was known in ancient times.

The Roman writer Palladius (34) records how lime is made from a hard white stone or Tiburtine, or dove coloured river stone or from marble; and Cato (7) gives instructions for the building of a lime kiln. Probably however, lime was not much used on soils till the time of Pliny. In his ~~Secundus~~ Naturalis Historia , Pliny (37) comments on the benefit of lime to vines and olive trees and advises that it be applied to the roots of cherry trees to hasten fruit ripening. He also writes approvingly of the chalking system employed by the Belgae on their corn fields. Marl was unknown to the early Romans in their own country but Pliny had learned of its use by the Greeks and the Britons and Gauls. He says "There is a way of nourishing earth by earth which has been found out in Britain and Gaul. It is thought that there is a greater degree of fruitfulness in this than in any other. It is a richness of earth, like the kernels in animal bodies, that are increased by fatness. The Greeks have not omitted to mention this; for is there anything that has not been tried by them? They call the marl like white clay "leucargillon", which they use in the lands near Megara, but only where they are moist and cold." Elaborating on the British practices he continues ".....When the field on which it is laid is in corn, it produces no other kind of plant. It

It lasts thirty years. If laid on thicker than Signinian plaster commonly is, it destroys the soil by giving it too much richness."

After Pliny's time the subject of liming disappears from the records for a long period. It is uncertain whether calcareous materials ceased to be employed to any extent for soil improvement or whether they merely escaped the attention of writers. The latter is more probable.

Wilson (50) cites Pellissy as being the next writer who again mentions lime. He (Pellissy) in the early part of the 16th century tells of his own use of it in the Ardennes, advising that it be applied as a compost on moist lands. However, we do find an earlier reference than Pellissy's, for it is recorded (14) in 1321 that on the Berkeley Estates lime was used on heavy clays or for the destruction of moss and that the value of marl in improving the texture of sandy soils and some kinds of clays had been recognised in the fortieth year of Henry III. The cost however, was considered excessive. Fitzherbert (15) writing two hundred years later says "marl is an excellent manure, and ...... exceeding chargeable."

The knowledge of the value of marling and liming in general, gradually spread and was practised where supplies were conveniently available but another two hundred years elapse before we find much reference to the virtue of lime for specific crops. In 1645, Sir Richard Weston, one of the greatest pioneers of Agriculture, in his "Discours of Husbandrie used in Brabant and Flanders" (48) recommended that for the cultivation of clover (which he was instrumental in introducing to Britain after his return from exile) the land should be pared, burned and limed. His advice as regards liming is still accepted as sound.

A few years later (1651) Hartlib (20) who as Ernle points out had pirated Weston's work, lists twenty natural substances which experience had proved to be of value as manures. These include chalk, marl, lime, "snagreet" or river soil largely mixed with small shells and used extensively in Surrey, and sea sand as employed in Cornwall. The last substance, most probably owed its value like "snagreet" to an admixture of calcareous shelly material.

With a gradually increasing population and the slow but persistent trend upwards of the standard of living as the centuries passed, there arose the necessity for ever increasing production from the land. Now although the use of organic manures and materials containing calcium had been known from time immemorial and although agricultural writers freely recommended them, the extension of their employment was definitely limited by the supplies available, and only the latter were capable of much increase. Thus, we find in the 17th and 18th centuries, liming becoming more and more recognised as a regular farm operation and the amounts applied increasing enormously. As late as the middle of last century Stephens (44) writes "On light turnip soils, some think 120 bushels (4½ - 6 tons)[*] per acre sufficient, whilst I have used 150 bushels (5½ - 7½ tons) with benefit. I have seen as much as 510 bushels (19 - 25½ tons) applied to the acre of wheat land, with manifest advantage. But perhaps 150 to 240 bushels (5½ - 12 tons) may be considered average quantities from the lightest to the heaviest soils. On weak moory soils, 75 bushels (3 tons) are enough with which to commence its improvement."

In Essex we read of 15 cart-loads of 40 bushels

[*] The applications expressed as tons per acre have been inserted by the present writer.

each (approximately 20 tons) as being a full dressing of chalk per acre on clay land, while in Hampshire it is said, 2000 bushels per acre were wheeled on to the land in barrows. Obviously on the score of expense such heavy applications could not be given at very frequent intervals. The usual practice was to apply it at, or near the beginning of the lease* of the farm so that the benefits might be reaped throughout the whole tenancy. In spite of this, cases occurred not infrequently towards the end of the 18th and beginning of the 19th centuries where injury was caused by over-liming.

In 1788 Dickson (11) remarks, "But whether there is a particular method of applying lime to prevent its bad effects, or whether there is any way of managing land worn out with lime, so as to restore it to its original state, and prepare it for another liming, is uncertain. These things can be found out only by experiments; but to finish these experiments too many years are necessary."

As far as can be gathered the damage to the soil appears to have been a physical rather than a

* Leases, at the time referred to, generally extended to upwards of 20 years.

chemical one, and was confined to soils of a naturally open texture which were continuously under the plough. While it had been learned by experience that lime, up to a point, improved these soils - which as we now know was partly due to the binding effect of the calcium compounds on the ultimate particles and the formation of the desirable "crumb structure" (8) - it was not sufficiently realised how much the decomposition and disappearance of the humified organic matter, which in itself has a most important cementing and moisture retentive function in such soils, was accelerated. Thus the heavy liming and frequent cultivations without any compensating operation led to a breaking down of the soil aggregates so that too great a looseness and friability resulted. Also, though we have not found it mentioned in the writings, we have observed in cases of applications of calcium carbonate in excess of 10 tons per acre on comparatively coarse textured soil that the surface readily tends to cake and crack on drying after rain. The practical methods of restoring a satisfactory structure as is fairly well understood by modern farmers, is by the direct application of farmyard or other organic manure, or the feeding of stock on the land whereby organic matter is added with simultaneous consolidation of the surface through trampling.

Although dressings of lime, which we now consider very heavy, were accepted as normal at the time under consideration, they were not without their critics. Purvis, the French Agricultural Chemist says - "While in France we are content to give from a thousandth to a hundredth of lime to the tillable soil, from ten to one hundred hectolitres to the hectare, they give in England from one to six hundredths or from one to six hundred hectorlitres to the hectare. The full success of the method of our country might make us regard the English method as an unnecessary waste."

The middle of the 19th century saw the commencement of vast changes in agricultural practice - and amongst others a diminution of this "unnecessary waste."

The real starting point of the revolution may be taken as 1840 when Liebig (27) outlined the relations between the composition of the soil and the nutrition of plants, and advanced his mineral theory. Certainly before this time, in addition to lime, chalk, marl and farmyard manure, a few substances such as hoofs and horns, shoddy, salt, saltpetre, soot and bones were known and used to a slight extent. Even Peruvian guano made its appearance in 1835 though in negligible quantity. But the attitude of agriculture to Chemistry was either unsympathetic or uninterested. However, the enthusiasm raised in certain circles for Liebig and his discoveries gave Agriculture its first hint of the possibilities that might lie behind the advancement of chemical knowledge. The ball thus set in motion gained tremendous impetus by the work of Lawes and Gilbert in the laboratory, the factory and the Agricultural Experiment Station.

Leibig had in 1840 suggested the sulphuric acid treatment of bones. This idea was extended to mineral phosphates and as a result of the remarkable effects produced in crop growth at the Rothamsted station (18), Lawes set up his factory at Bow and began the manufacture of superphosphate on a commercial scale in 1843.

Lawes' success led to other substances being tried out, manufactured and put on the market. Thus a great and expanding industry came into being. The gentle persuasive advice of the scientist was supplemented by the importunities of the persistent and "unrebuffable" salesman so that the innate conservativism of the farmer was at least partly broken down.

Once "artificial fertilisers" had been tried and the initial mistakes of using compounds unsuited to specific cases had been recognised, the employment of manufactured fertilisers became a regular part of agricultural routine. The amounts and varieties used steadily increased and there entered that period of British Agriculture known as the time of "High Farming".

Coincident with the expanding use of fertilisers, the principles of land drainage were being explored and considerable areas, which in their old semi-waterlogged condition would have given a disappointing response to the new manures, were brought to a state of productivity by the removal of the stagnant water.

These and other far reaching innovations inevitably caused radical and fairly quick changes in the old system of farming. Traditional practices were modified or abandoned to make way for those based on the new knowledge and to supply the growing needs of an adjacent industrial population. Again, farming was no longer simply a means of providing subsistence. Industrialism taught farmers to strive for a "profit" - something over and above what was required to keep the business running. It followed from this that operations requiring capital outlay and from which the returns were slow were not embarked on lightly. Liming fell within this category.

Liming however had previously been regarded almost as a sine qua non for successful crop production, but so efficient had the manufactured fertilisers proved that it is hardly to be wondered at that, in many cases, the belief grew that they, together with farmyard manure, supplied all that was required. Thus gradually the applications of lime were reduced or omitted.

A further contributory cause of the falling away of the old practice was the recurrent periods of acute adversity which British agriculture suffered between the years 1874 and 1912 due variously to the ups and downs of the country's industry, to successions of unfavourable seasons and to competition from new countries with extensive tracts of virgin land. In these days there was insufficient money for necessities, not to speak of "extras" as liming had come to be largely regarded.

Readjustment was gradually taking place and agriculture was settling down to the position allocated to it by the immediate needs of the industrial population when mankind was smitten with madness like the swine of old and stampeded over the cliffs of war. Gone then for the "duration" was the remotest possibility of any activity except such as yielded immediate results. Liming was out of the question. Such lime kilns as produced for agricultural purposes solely, closed down and many still lie derelict.

During the war every means available was utilised to make the land yield up its capital. Fertilisers were very limited. The raw materials for sulphate of ammonia were required for munitions. Basic slag remained unground. Only small imports of rock phosphate were possible. The supplies of potash were cut off. Where possible, temporary substitutes were used, such as common salt (36) in place of potash manures. But the device most widely employed (partly under State control) was that of ploughing up land which previously had lain long as pasture.

At the close of the war the land as well as the people were showing signs of exhaustion. The agricultural industry had temporarily benefited financially from its position of vital importance. The stage was set - other things concurring - for a boom in fertilisers. The boom materialised in this as in other spheres. Fertilisers were bought and applied lavishly - particularly those containing nitrogen. Much of the land broken out of old pasture was for a time kept under the plough and cropped intensively. The prices ruling for agricultural produce made this procedure possible and kept active much land just on the "margin of cultivation". But what of lime during these years? A little was used but it was expensive. The demand was not sufficiently strong to cause a re-opening of local kilns and freight and other charges rendered the cost prohibitive at distances far from the centres of production.

A habit once lost is not always easy to recapture. Liming was not now a regular practice and by the time there was any widespread realisation that the land was beginning to "cry for lime" the tide of prosperity had turned and was ebbing rapidly. Much of the land sank below the level of profitable cultivation and was either seeded out as permanent pasture or was allowed to "tumble down" in its own way. The fall in farming profits was only one aspect of a general depression and to obtain a market the price of fertilisers had to fall too. Thus fertilisers were never quite outwith the farmers' reach and the attempt was made - encouraged by the fertiliser trade - to meet the difficulties by an increased rate of production from the smaller arable area. All this time the depletion of the calcium content of the soil was continuing. The situation over large areas was aggravated by the lack of drainage or the state of disrepair into which old drains had fallen. That the conditions were detrimental to crop production and wide-spread is indicated by the fact that the Government (26) actually gave financial assistance for drainage operations.

The post war years saw a greatly increased activity on the part of educational and scientific bodies which were concerned with the problems of agriculture. Innumerable experiments (e.g.51) were conducted and demonstrations arranged to teach the farmer something new or remind him of what had been forgotten. The subject of liming was frequently in the foreground and all over the country the same general conclusion was reached - that a serious deficiency of lime existed.

PASTURE and PASTURE SPECIES.

The vast increase in the area under grass of various sorts has raised the importance of all questions relating to it. Between 1866 and 1930 the area under permanent pasture in England rose from 8.99 million acres to 15.78 million acres (14) (2). While in Scotland and Wales a corresponding rise took place. Much of this extended area - and particularly that which has reverted since the war - is in a very impoverished condition, with great detriment to the stock-carrying capacity of the country.

That the actual feeding value of herbage as indicated by the stock carrying power and the chemical composition varies greatly from place to place according to the available supply of plant nutrients and the treatment given, has been abundantly proved by Orr (31) and his co-workers. The following abridged table after Godden (32) illustrates the point -

COMPOSITION of PASTURES
% of Dry Matter.

-	CaO	P_2O_5	Protein
Average of 24 cultivated pastures.	1.004	.735	17.656
Scottish Lowland pasture..........	.57	.65	15.25
35 Scottish pastures) Eaten	.56	.60	15.8
35 Scottish pastures) Not eaten	.30	.37	11.4

The investigations of the Rowett Research

Institute have of late years strongly emphasised the importance of the mineral content of grazings not only in their ability to support an adequate population but to maintain the individuals in health. In a discussion of the changes in distribution of live stock in Scotland during the past fifty years, Greig (17) points out that the sheep population of Argyll, Inverness, Ross and Cromarty, Sutherland and Perth has declined by 22.7 per cent., while other districts show a compensating increase. One factor contributing to this re-distribution he considers is the diminution of mineral constituents in the higher grazings. Added weight is given to the importance of the calcium of the plant by the conclusions of Elliot, Orr and Wood (12) from their study of the mineral content of pastures. They state, -

"Sheep in grazing choose pastures whose mineral content most closely approximates to that of good cultivated pastures."

"In most of the pastures collected from the West Highlands and the Falkland Islands the mineral element most deficient was calcium."

"Young sheep on a diet deficient in calcium fail to grow at the maximum rate."

The influence of treatment is brought out by Orr's (30) figures.

PERCENTAGE of DRY MATTER

Fertiliser applied	Pasture on Poor Moorland Soil		Pasture on Good Cultivated Soil	
	CaO	P_2O_5	CaO	P_2O_5
Nil (Control)......	.59	.29	1.16	0.96
Lime................	.77	.30	1.37	0.92
Superphosphate.....	.94	.71	1.16	0.93
Lime plus superphosphate........	.89	.73	1.56	0.92

It early became apparent - more particularly so to specialists - that pasture was not simply a community of similar plants. Thus we find that in this country over a hundred years ago (27a) attention began to be given to a number of species to be included in mixtures of seeds for the production of hay and grazing for stock. Then towards the end of last century botanists made clear the morphological distinctions between the various species and so the truth gradually dawned that a sward was not something homogeneous but a very mixed assemblage. But "knowledge is a slow growth". To the majority of farmers and even to most scientists, unless possessed of some botanical training, grass was grass and that was it more or less disposed of. This attitude has persisted up to quite recent times and it is only the work of men like Gilchrist, Somerville, Percival and McAlpine, and at the present day Stapledon of the Welsh Plant Station and Findlay of the North of Scotland College of Agriculture, that has hastened its modification.

Studies in the field, such as those of Jenkin (23) dealing with the relative persistence of species when exposed to inter-competition and the selective influence of environment have helped to demonstrate that there must be inherent physiological as well as morphological differences between species. Though some of them are well known, many are not.

In the critical examination of species in relation to their suitability for different agricultural requirements, such as, for example, hay making as opposed to grazing, it has been found that even the species is far from being a stable unit but must be recognised as embracing a number of strains. Some of these strains are fairly distinct but many show only slight differences amongst themselves and a subsequent generation might lose the faint distinguishing character or assume a new one consequent upon a genetical re-arrangement resulting from the cross fertilization which is frequent in gramineae. In making selections of strains on the basis of some point of utility it is therefore obvious that the finer differences must be disregarded and only those which are likely to be perpetuated considered. It thus comes about that for practical purposes we deal with "types" which are really aggregates of strains whose range of deviation from some central value is fairly narrow.

The tendency of the more advanced farmers and their scientific advisers is to regard grass as a distinct crop in the same way as potatoes or oats and abandon the attitude that it is something unique which can, frequently unaided, battle successfully against an antagonistic environment and continue indefinitely to yield an adequate supply of animal nutriment. This being so it is obvious that the components of the crop - the individual species - must receive consideration.

The possibility of making some progress along this line has been increased in the case of seeded pastures by the reduction in the number of species which are included in a seeds mixture now as compared with the end of last and the beginning of this century. Elliot of Clifton Park (13) an authority of his day, recommended mixtures containing upwards of twenty species, whereas Stapledon (42) and Stapledon and Hanley (43) advise on occasions as few as two species. In general we find the current practice is to include six or seven species (including leguminosae). While this trend has made for simplification, the claims of several outstanding strains (or types) within each species has acted in the opposite direction.

If then it is agreed that the greatest yields can only be obtained by acting according to the peculiarities of the component species and strains, by associating together those which react most favourably to the dominating environmental factor and by modifying conditions so that the naturally less aggressive will compete more successfully with the more robust, then it follows that the characteristic responses of each,under a wide range of circumstances,must be known. But that is the root of all the difficulties in devising mixtures. There exists comparatively little accurate knowledge of responses of even the older and better known species, and practically none on the more recently isolated strains.

GENERAL STATEMENT of PROBLEM

In view of what has been advanced one may well be impressed by the importance of calcium compounds as a factor in promoting and maintaining healthy growth, and by the fact that the abundant applications of an earlier generation have been drawn on so long without repayment that much of the agricultural land at the present time is in dire need of replenishment. It must also be realised that in extent and value to the country as a food producing medium, grass is far in advance of any other crop. Recent work, too, has made it clear that species or in some cases strains are the units building up that crop. These facts and the consciousness of the insufficiency of the information regarding the varied responses of species and strains to lime led to the undertaking of investigations in the hope of adding something - however little - to the store of knowledge.

Broadly, the question asked was "How does grass, and particularly the individuals, react under conditions of deficiency, moderate supplies, abundance, or superabundance of calcium?"

That condition of a soil which would be improved for plants by the addition of lime is spoken of by agriculturists as "sourness" and by chemists as "acidity" though the latter term is becoming popular: where no need for lime is recognised, the land is said to be "sweet" or "neutral".

The more non-commital designations have in this case much to recommend them.

Now, examination shows that the floristic characters of sweet and sour land are often very different. On apparently sour land we frequently find such plants as Anthoxanthum odoratum, Festuca ovina, etc. associated with Juncus spp., Ranunculus spp., Luzula spp. etc. While on sweet land we are not surprised to find more luxuriant plants such as Lolium perenne, Poa trivialis etc. Russell (38) says "So far as this (the degree of tolerance to acidity) can be gathered from observation and agricultural experience it is set out...." The data relevant to pastures are here extracted.

DEGREE of TOLERANCE to SOURNESS or ACIDITY

England		Rhode Island (Hartwell & Damon) (21)	
Less Tolerant	More Tolerant	Less Tolerant	More Tolerant
Trifolium pratense. Alopecurus pratensis. Lolium perenne. Trifolium repens.	Dactylis glom. Anthoxanthum odoratum. Festuca ovina. Holcus lanatus. Rumex acetosa.	Trifolium pratense. Alopecurus pratensis. Poa pratensis. Dactylis glomerata.	Agrostis canina. Agrostis vulgaris.

Such information while useful in a general way is unsatisfying in its vagueness and leaves room for doubt, as almost all data collected in such a way must. From a consideration of the generalisations with which many practical agriculturalists satisfy themselves further questions arise. Thus, does a plant which is "less tolerant" show actual symptoms of injury in itself? May it not be that the percentage germination (in the soil) of seeds of that plant is lower but such plants as do grow are quite normal? Do less tolerant plants fade out entirely under extremely acid conditions? How far can they be stimulated by additions of calcium compounds? Do more tolerant plants show distress when the acidity is removed, and will they be entirely eliminated by heavy applications of lime? Or is it merely a question of competition? If lime be added to a mixed herbage what will be the increase, if any, in yield, from different amounts of lime - apart from any change that may be induced in the relative numbers of the component species? It is on these questions that an attempt has been made to supply some information.

SOIL ACIDITY.

As a preliminary, however, it is necessary to inquire into the nature of soil acidity. From the farmer's standpoint it is simply, as already stated, that soil condition which can be remedied by a sufficient application of lime. The investigations of soil chemists and physicists, however, seek to supply fuller information.

Early chemists took the unsophisticated view that sourness was simply due to organic acids resulting from the breaking down of plant residues under varying degrees of poor aeration. But it was found that sourness existed where there was little organic matter and where aeration was good. This led to the postulation of a mineral acid such as a complex silicic acid.

At a later stage - early in the present century - physical ideas were largely applied to soil phenomena. Definite evidence of free acid in the soil had not been obtained but the presence of humic and clay colloidal material was demonstrated therefore the theory was advanced that soil acidity was due to a preferential absorption of bases by the colloids. In support of this it was shown (35) that water extracts from acid soils were too slightly acidic to release acids from neutral salts. This property, however, is really one of the characteristics of acid soils. It was further held that such a reaction did not adhere to the stoichiometric laws.

These views have had to be considerably modified in the light of subsequent work. It was shown by Daikuhara (10) that the reaction between neutral salts and acid soils was simply one of base exchange and this, Truog (47) proved when all factors were allowed for, did adhere to the stoichiometric laws.

The ionic dissociation theory of Arrhenius (4) throwing new light on the nature of acidity has supplied the foundation on which the bulk of recent work on soil acidity is built. The limitations df ordinary titration are disclosed. Its value while measuring "the total quantity of hydrogen ions producible under the conditions of the experiment, supposing them to be neutralised or linked up with (OH) ions as quickly as they are liberated" takes no cognisance of the amount of dissociation which takes place in solution. Further, a definite "end point" may be unobtainable due to the presence of several slightly and variously dissociated acids. It is desirable therefore, in many cases to know actually the concentration of hydrogen ions present.

Since the dissociation of the cations and the anions sets up a difference in potential, the intensity of this dissociation can be measured electrometrically.

This is usually done by apparatus employing the hydrogen electrode. Rapid indirect methods of measurement (9) (38) (45) have been devised but results from these are at best only approximate and frequently unreliable.

At neutrality the concentration of hydrogen ions equals that of hydroxyl ions which physical measurements have shown to be $10^{-7.07}$ gram-ions per litre. With rising acidity the hydrogen ions exceed this, with alkalinity the hydroxyl ions. The numbers are so great that for convenience Sőrensen's (41) device is applied of using minus the logarithm, that is the logarithm of the reciprocal rather than the number itself. The figure thus arrived at is known as the pH value.

The fact that an acid soil in aqueous suspension displays a definite hydrogen ion concentration, thereby indicating a certain amount of dissociation and the various phenomena surrounding the development of acid on treating soils with salt solutions have led to the concept of the colloidal absorbing material as "acidoid" in nature. That is, the colloidal particle is visualised as being composed of a large central negatively charged core or super anion holding at its surface absorbed metallic cations. If the quantity of metallic ions present is not sufficient to neutralise all the "surface acidity" then dissociated hydrogen ions will appear side by side with the others as surface-bound cations. There will therefore be a maximum dissociation capacity for any soil depending on the area of the absorbing surface and it also follows that there will be a whole range of "salts" from the point where metallic cations begin to replace the hydrogen right to the complete satisfaction of the combining power of the acidoid anion with such cations. The idea is well illustrated by Page (33). If the acidoid anion be represented by (Ac), the total absorbing capacity as 100, cations other than hydrogen by $R^{\cdot}$ and the proportion of the capacity occupied by these by x then

$$(Ac)\ 100\ H^{\cdot} \rightleftharpoons (Ac) \begin{matrix}(100-x)H^{\cdot} \\ xR\end{matrix} \rightleftharpoons (Ac)\ 100\ R^{\cdot}$$

It appears that the acidity which a soil will develop depends on the total absorbing capacity and the relation between the proportions of that capacity which are occupied by hydrogen and metallic cations.

The observations of Kappen (25) led him to postulate four kinds of soil acidity which he has named "Hydrolytic Acidity", "Exchange Acidity", "Neutral Salt Decomposition" and "Active Acidity", but on close examination and the admission of hydrogen as an exchangeable cation the differences between these emerge as being of degree merely and not of kind.

At first sight it would appear to be a simple chemical operation to measure the amount of hydrogen present but the hydrogen ion appears to be much more strongly held by the absorbing complex than the Metallic ions. Again such a measurement gives no information on the amount of bases present unless the total absorption capacity is known. Further, it is believed that for completely successful growth only about half the total capacity need be occupied by bases, though information as to the optimum percentage for specific plants is extremely scanty.

LIME REQUIREMENTS.

While investigations into the fundamental nature of the soil complex and soil acidity have been proceeding there have been from time to time attempts to apply the available knowledge to the problem of ascertaining just how much lime should be given to an acid soil to bring it to a satisfactory condition for plant growth. The desirability of having definite figures based on some accurate measurement of the soil properties is patent, no matter what success has attended empiricism in the past.

Realising that the interaction of lime with soil was an absorption phenomenon, Hutchinson and McLennan (22) devised their method of measuring the "lime requirement" of a soil. A weighed quantity of soil was treated with a weak solution of calcium bicarbonate and after regular shaking for a specified time an aliquot portion of the filtrate was titrated. From the difference in strength of the filtrate and the original solution the amount of calcium carbonate absorbed was calculated as a percentage of the soil. Taking an average figure for the specific gravity of soil and its depth as nine inches, each 0.1 per cent represents in the field approximately 1 ton per acre.

This method has been largely employed and is the one adopted most generally throughout Britain. It makes no direct measurement of acidity but simply states how much lime the fine particles of the soil can absorb under the conditions of the test. There is practically no information in this country, so far as can be gathered, as to how vegetation has responded to treatment based on this test compared to other rates of liming.

At a later date Hardy & Lewis (19) adopted the plan of determining the amount of lime required to reduce the acidity of soils to a pH of 7.0. They proceeded by treating the soil sample with neutral calcium chloride solution and by adding calcium hydroxide successively at short intervals. Using the quinhydrone electrode, the pH value is taken after each addition of hydroxide until an alkaline reaction is obtained. By plotting the results the amount of calcium hydroxide and hence calcium carbonate required to give pH 7.0 can be read off, and expressed as before as a percentage of the soil. The values obtained by this method are usually higher than by the Hutchinson and McLennan method. Determinations are however made much more rapidly and in the process the pH value of the soil is recorded.

While a pH of 7.0 does not necessarily mean that the saturation capacity of the soil has been completely taken up by bases to the total exclusion of hydrogen, the Hardy method does supply a "lime requirement" figure which may more nearly approach that than the previous method discussed and certainly that part of the capacity which is, so to speak, at all eager for bases will be satisfied. Perhaps even more so here than in the earlier case mentioned, is there a lack of information as to the floristic reactions under British climatic conditions from treatment at rates indicated by the Hardy test.

RECENT WORK

Results of work closely pertinent to that detailed later are not numerous but the more important are here noted.

At Rothamsted (5) (38) figures bearing on the present discussion have been collected from the experimental hay plots. In most instances, the effects of lime plus fertilisers were being observed but some data are available where lime alone was used. The plots of course contained a mixed population, and the interest lies in noting how the lime has changed the pH value and the percentage of each species contributing to the herbage. An abridged table is given below:-

INFLUENCE of LIME alone on pH VALUE and HERBAGE of ROTHAMSTED GRASS PLOTS; 1919 RESULTS.

	No Lime	Lime
pH of surface soil..........	5.72	6.88
pH of subsoil...............	6.16	6.58
	per cent	per cent
Agrostis Vulgaris...........	8.34	1.53
Alopecurus pratensis........	0.29	0.61
Anthoxanthum odoratum.......	6.97	3.06
Arrhenatherum avenaceum.....	0.29	0.51
Dactylis glomerata..........	8.34	7.35
Festuca ovina...............	6.68	5.01
Holcus lanatus..............	9.13	7.66
Poa pratensis...............	0.15	1.94

Olsen (29) endeavoured to show a connection between the distribution of plants and the Hydrogen-ion concentration of the soil by noting the percentage frequency with which the various species occurred on the different areas which he examined. Russell has made use of some of his figures from which a selection is here given:-

AVERAGE FREQUENCY of MEADOW SPECIES on SOILS of DIFFERENT pH VALUES.

pH Class	3.5 - 3.9	4 - 4.4	4.5 4.9	5 - 5.4	5.5 - 5.9	6 - 6.4	6.5 - 6.9	7 - 7.4	7.5 - 7.9	No.of Localities.
Deschampsia flex......	86	68	40	-	-	-	-	-	-	13
Calluna vulgaris..	20	47	10	20	-	-	-	-	-	13
Agrostis canina....	-	100	100	73	48	45	10	20	-	39
Festuca ovina.....	-	100	47	35	20	20	50	-	-	12
Anthoxanthum odoratum..	33	47	79	80	83	76	27	30	30	46
Deschampsia caespitosa	-	-	-	40	67	62	33	52	23	33
Agrostis alba......	-	-	-	-	-	-	30	65	60	7

In an extensive survey of farms in Sweden, Arrhenius (4) found that each particular crop was frequently and successfully cultivated within certain limits of soil hydrogen-ion concentration and that beyond these limits the crop was not so commonly or so successfully grown. Thus he learned that the successful growing of Barley was most usual between pH 6.6 and 7.5; Wheat between pH 6.0 and 7.5; Oats between pH 4.7 and 6.2; Rye between pH 4.6 and 5.8; Timothy between pH 4.7 and 5.8.

Such work as has been done along the line of correlating plant growth with "lime requirements" has consisted mainly in observing the prevalence of certain species or associations and testing the soil in that particular vicinity; or, which is almost the same, testing a number of soils and observing the species which flourished on each. In an investigation conducted on this principle on Harpenden Common by Hutchinson & McLennan (22) they found the following:-

LIME REQUIREMENT and VEGETATION

Average L.R. of Soil	Dominant Flora
Approx. 0.22 per cent $CaCO_3$	Trifolium repens.
" 0.26 " "	Festuca ovina et rubra.
" 0.39 " "	Gorse.
" 0.43 " "	Holcus lanatus.
" 0.53 " "	Rumex.

In a somewhat similar enquiry in Woodlands, Salisbury (40) found Holcus, Anthoxanthum and Cnicus at a Lime Requirement of 0.52 and Holcus and Anemone at 0.62 per cent calcium carbonate.

Such results are of great interest and it is unfortunate that floristic data where the Hardy lime requirement method was used are not available for comparison with those which are presented in the following pages.

EXPERIMENTAL

DETAILS of PROCEDURE and FINDINGS with DISCUSSIONS of RESULTS

POT EXPERIMENTS

Long before the commencement of our enquiries dealing more particularly with the influence of the lime status on the response of grasses, it was fully realised that under field conditions a great many apparent inconsistences in behaviour existed. These inconsistences might arise from differences in any of the many environmental factors such as inherent soil peculiarities, geographical and topographical situations, cultural treatments and grazing; or from diversity of genetical constitution. Only to a limited extent, as previously pointed out, can genetical uniformity be obtained but by the expedient of pot culture environmental differences can be reduced to a minimum. Moreover in the case of grasses the diversity of conditions under which they grow, make it certain that though the particular strain is important, the influence of environment is even more pronounced.

PURPOSE of EXPERIMENTS

To observe the response which the principal pasture species make on acid soil to additions of lime, three series of pot experiments were conducted. The first series was devised for observation of the effects of increments of lime up to three times the amount indicated by the Hardy lime requirement test. The second series, carried out at a later date, was intended to supply confirmation of certain observations made on the first series, to test the effect of lime on seedling numbers, and to give comparisons between strains of a few species. In the third series the object was to discover whether growth were adversely affected by large amounts of lime.

POT EXPERIMENTS - Series I.

Procedure and Observations.

In Series I ordinary commercial seeds of the following species were used:-

(1) Lolium perenne, L.
(2) Dactylis glomerata, L.
(3) Phleum pratense, L.
(4) Festuca elatior, L., sub sp. pratensis, Hackel.
(5) Cynosurus cristatus, L.
(6) Poa trivialis, L.
(7) Agrostis vulgaris, With.
(8) Festuca ovina, L.

The soil for this experiment which may be described as a light humus loam, was obtained from Braco in South Perthshire. The particular field from which the soil was taken had not been limed within memory and was completely overrun with Agrostis. On testing, the pH value, lime requirement and loss on ignition were found to be -

pH4.9
Lime requirement (Hardy) 0.416% $CaCO_3$
Loss on Ignition 15. 3%.

Using the lime requirement as the unit rate of liming, the soil treatments for each species were -

(1) Control - No lime.
(2) Calcium carbonate at lime requirement rate.
(3) Calcium carbonate at twice lime requirement rate.
(4) Calcium carbonate at thrice lime requirement rate.

Seven inch, unglazed earthenware pots were employed. A suitable weight of soil per pot was found to be 1800 gms. The amounts of lime per pot were calculated accordingly. For convenience of soil treatment and observation of early growth the initial stages of the experiment where carried out in the Horticultural Laboratory of the West of Scotland Agricultural College. Later, the pots were transferred to the gardens at Auchincruive, Ayr, where each was sunk to the rim in the ground.

Seeding took place at the middle of May and eight days later shoots began to appear. After a further six days most of the species had made sufficient growth to allow of comparing the initial effects of the treatments.

Progress was noted at regular intervals throughout the two and a half years of the experiment's duration. The observations on each species are summarised below. (The letters L.R. are used to indicate lime requirement.)

Lolium perenne. The seedling growth was decidedly more vigorous and profuse on the treated pots than on the untreated. Differences amongst the treated pots were not very strong at first but 2 L.R. was slightly better than either 1 LR. or 3 L.R. Right from the seedling stage to the conclusion of the experiment "No lime" gave consistently the poorest growth, the difference between it and any other treatment always being quite obvious. With the passage of time the difference became more marked and the plants showed a

Photograph 1.

Lolium perenne.
June of second
year. Left to
right; Control,
1 L.R., 2 L.R.,
3 L.R.

Photograph 2.

Dactylis glomerata.
June of second year
Left to right;
Control, 1 L.R.,
2 L.R., 3 L.R.

Photograph 3.

Dactylis glomerata.
May of third year.
Left to right;
Control, 1 L.R.

tendency to die off when weather conditions were in the least abnormal.

The results from the other treatments were less definite. While 3 L.R. gave the greatest summer and autumn growth it was followed closely by 1 L.R. which during mid-winter was greenest and showed most growth. 2 L.R. did not maintain its initial advantage. It was surpassed at the end of the first year by 1 L.R. and 3 L.R. By the second year it was much behind either of these, but by the third year it had fully made up the leeway and was quite as good as the others. (Photograph 1).

On the whole, such differences as existed from time to time between 1 L.R., 2 L.R. and 3 L.R. were levelled up till, at the conclusion of the experiment, no one could be claimed as superior to the others.

Dactylis glomerata. The "No lime" treatment gave for this grass also the poorest results throughout. The difference between "No lime" and any other treatment was at all times very marked.

At the seedling stage there was only a faint shade of difference between 2 L.R. and 3 L.R. though what little there was, was in favour of 2 L.R. The order at this period was 2 L.R., 3 L.R., 1 L.R. and "No

Lime". These positions were maintained right on to the autumn (September) of the first year.

By late autumn (November) all suffered considerably from "winter-burn"* though 3 L.R. was least affected, and by mid-winter all were strongly "burned", but the difference in growth between "No lime" and 3 L.R. was still very noticeable.

The following year (Photograph 2) satisfactory growth was given by all lime treatments while "No lime" was still poor. 2 L.R. and 3 L.R. were slightly denser than 1 L.R. During the next winter the same relative susceptibilities to winter-burn as formerly were noticed though the difference between 3 L.R. and the other treatments was rather stronger and in spring, 3 L.R. having suffered least started into fresh growth earliest and most vigorously. This was followed by 2 L.R. with 1 L.R. only a little later. The same profusion and denseness of growth on 2 L.R. and 3 L.R. as before were carried into the third year, while the lack of lime (Photograph 3) still depressed the growth, the plants remaining weak and stunted and retaining the burn late into the spring.

Phleum pratense. Again the "No lime" treatment gave the poorest results over the whole period of the

* The browning and withering of leaves.

Photograph 4.

Phleum pratense.
June of second year
Left to right;
Control, 1 L. R.,
2 L. R., 3 L. R.

Photograph 5.

Festuca pratensis.
May of third year.
Left to right;
Control, 1 L.R.

Photograph 6.

Festuca pratensis.
May of third year.
Left to right; 2
L.R., 3 L.R.

trial. The initial order of growth, that is at the seedling stage - 2 L.R. and 3 L.R. equal, 1 L.R., No lime - was fairly well maintained throughout the summer and autumn though the growths on 1 L.R., 2 L.R., and 3 L.R. were all so strong that the differences were slight and 1 L.R. seemed to be overhauling 2 L.R.

In late autumn and on into mid-winter the greenness was well maintained and likewise the better growth from the lime treatments, - especially the 3 L.R.- over the "No lime".

The following year the benefit of the lime was still manifest though the slight falling back of 2 L.R. which had been noted the previous autumn became somewhat accentuated especially as the plants grew into ear (Photograph 4). Moreover the early difference between "No lime" on the one hand and 1 L.R. and 2 L.R. on the other was not now so great, and by the spring of the third year though it still persisted it was not very pronounced. The 3 L.R. showed up to great advantage.

Festuca pratensis. As in the previous cases the growth without lime was poorest from first to last. 1 L.R. made slightly better growth in the seedling stage than 2 L.R. and 3 L.R. but as the plants grew more mature the differences between the lime treatments became less marked.

A noticeable feature with this grass was the incidence of winter-burn. By late autumn, burn was showing strongly on the controls but on all others the lime had apparently delayed it; by mid-winter, however, all were much affected though not nearly to the same extent as the controls.

The advantage gained from the lime continued to be evident till the conclusion of the trial (Photograph 5) but no additional benefit accrued from the heavier rates (Photograph 6).

Cynosurus cristatus. At the first stage, 2 L.R. and 3 L.R. were a very little before 1 L.R. and all showed earlier and stronger growth than "No lime". At a later period 3 L.R. had the most vigorous growth but this was not maintained (Photograph 7). All showed severe winter-burn in late autumn but as the winter progressed this was seen to be more pronounced on the controls than where lime had been applied. While 3 L.R. could not be said to produce a greater bulk than the others, the grass from this treatment started into growth earlier in spring giving plants much taller and greener than the others.

Photograph 7.

Cynosurus cristatus. June of second year. Left to right; Control, 1 L.R., 2 L.R., 3 L.R.

Photograph 8.

Poa trivialis. June of second year. Left to right; Control, 1 L.R., 2 L.R., 3 L.R.

Photograph 9.

Festuca ovina. June of second year. Left to right; Control, 1 L.R., 2 L.R., 3 L.R.

Poa trivialis. The seedling growth order - 3 L.R., 2 L.R., 1 L.R. and "No lime" was maintained throughout summer, autumn and winter and was still evident the following year when the plants reached maturity (Photograph 8). The growth on 3 L.R. and 2 L.R. was always very strong and dense, whereas on 1 L.R. and the controls it was much weaker and opener. Winter-burn strongly affected all, though "No lime" suffered more severely than the others. Even at mid-winter there was a progressively stronger growth with increasing lime.

Festuca ovina. This was the only species tested where the initial growth appeared to be retarded by the heavier amounts of lime. 1 L.R. however gave practically the same effect as "No lime". The same order - progressively poorer from "No lime" to 3 L.R. - persisted till the first autumn. At this time though all remained very green the "No lime" began to show just traces of burn. By mid-winter it was decidedly more burned than the others. The freedom from burn where lime was given, especially 3 L.R., allowing better survival of the winter, enabled growth to commence earlier. (This was noticed in both the second and third years.) As a result of this, flowering occurred sooner on the limed pots (Photograph 9) but by the time this was taking place the "No lime" had quite as much leaf development as the others and was slightly greener.

Agrostis vulgaris. At the first stage 3 L.R. had the best growth, the others being equal. Growth was very slow but by autumn the controls were slightly better than the others. Very little winter-burn was shown by any. As the trial progressed the growth on the limed pots was a little thicker than on the "No lime", though at no time was the difference very marked. In Spring the "No lime" was greenest.

POT EXPERIMENTS - Series II.

Procedure.

Whereas in Series I only one soil was used, in Series II, three soils were employed so that the behaviour of the various grasses might be observed on soils of different character, not only in their original untreated state but after additions of lime to counteract their acidity.

The first soil, obtained from Morriston, South Ayrshire, was light and friable tending to be finely sandy with a rather low organic matter content and decidedly acid as indicated by the lime requirement and the pH value. It will be referred to as the "Morriston" soil.

The second was obtained from Ladymuir, West Renfrewshire and will be referred to as the "Ladymuir" soil. It tended to be peaty in character, having a very high organic matter content and being very strongly acid. The third soil, from Eastwood, East Renfrewshire was a clay loam containing an amount of organic matter between those of Morriston and Ladymuir and having only a very faint acidity.

TABLE I. SOIL DATA.

Soil	Lime requirement % $CaCO_3$	pH value	Organic Matter.* (% loss on ignition)
Morriston..	.300	4.98	6.5
Ladymuir...	1.02	4.27	32.5
Eastwood...	.042	6.45	13.7

SOIL TREATMENT

In view of the fact that in Series I although a decided benefit was usually obtained from lime there was not always much additional gain from increments up to three times the lime requirement; and in order to keep the experiment within manageable dimensions a jump was made from 1 L.R. to 4 L.R. omitting intermediate

* Organic matter is taken throughout as equivalent to loss on ignition.

increments on the acid soils. To Eastwood soil, having practically no lime requirement no treatment was given in this experiment. (In a subsequent experiment, to be noted later, heavy increments of lime were given.) The soils and treatments on which each species or strain was grown were therefore as follows:-

Morriston: Control - No lime, 1 L.R., 4 L.R.
Ladymuir: Control - No lime, 1 L.R., 4 L.R.
Eastwood: No treatment.

SPECIES and STRAINS

Of late years the question of the particular strain of a grass used has become of considerable importance. Investigations so far have been mainly along the general lines of relative permanence and suitability for either hay production or grazing. Apparently few attempts have yet been made to ascertain the influence of the various soil factors on different strains of the same species.* As soil acidity is a factor which has to be reckoned with on so many soils where these grasses are required to grow, it was decided to test the response to lime of the principal strains of the more important species.

* Since writing the above, the Welsh Plant Breeding Station has issued the results of trials with pedigree strains of herbage grasses, where the effects of nitrogen are compared. Bul.13.Series H.

The species and strains studied in this series were -

TABLE 11. SPECIES and STRAINS. SERIES II.

Species	Strain
Lolium perenne, L.	Ayrshire
Lolium perenne, L.	Kent Indigenous
Dactylis glomerata, L.	Danish
Dactylis glomerata, L.	New Zealand
Dactylis glomerata, L.	Welsh*
Phleum pratense, L.	Scotch
Phleum pratense, L.	Gloria.
Phleum pratense, L.	Welsh*
Alopecurus pratensis, L.	-
Poa trivialis, L.	-

For each pot, fifty apparently sound seeds were counted out and planted at regular intervals half an inch below the surface. As the seedlings appeared, counts were made on each pot at intervals of a few days. This was repeated until no further increase in the numbers was obtained. These numbers were compared with the official germination percentages. When crowding began the plants were thinned out. In every pot certain plants tended to be taller and more robust than their neighbours but the plants allowed to remain were, as nearly as could be judged, average for their particular pot.

The measurements and observations on each of the grasses are given in the order in which these are

* Strains emanating from the Welsh Plant Breeding Station.

mentioned in Table 11. The seeds were sown on May 22nd in all cases with the exceptions of Alopecurus pratensis and Poa trivialis which were sown two days later.

LOLIUM PERENNE

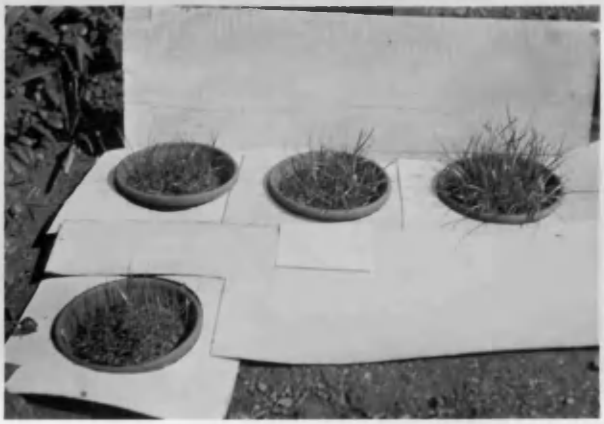
TABLE III. LOLIUM PERENNE - AYRSHIRE.

Seedling Counts as Percentage of Seeds sown. Official Germination, 91%.

Soils	Morriston			Ladymuir			Eastwood
Treatments	Control	1 L.R.	4 L.R.	Control	1 L.R.	4 L.R.	Nil
Days after sowing							
10	64	83	90	72	88	90	94
15	80	88	92	72	88	92	94
17	82	88	92	78	88	92	96
22	82	88	92	76	86	94	96
39	64	86	92	72	86	94	88

In the earliest stage the plants were strongest on Ladymuir 4 L.R. Growth here was very regular and at 10 days after sowing, the shoots were from ½" to ¾" in height. Next in appearance and almost as good, was Morriston 4 L.R. Morriston 1 L.R., Ladymuir 1 L.R. and Eastwood were equal at ¼", while on the Morriston and Ladymuir controls the shoots were just emerging from the soil.

During the next month growth proceeded contin-



Photograph 10.

Lolium perenne - Ayrshire. July. Back, Morriston soil, left to right Control, 1 L.R., 4 L.R., Front; Eastwood soil.

Photograph 11.

Lolium perenne - Ayrshire. Morriston soil. July. Left to right; Control, 1 L.R., 4 L.R.

Photograph 12.

Dactylis glomerata Danish. Morriston soil, July. Left to right; Control, 4 L.R.

uously and rapidly on the Morriston and Eastwood soils while on the Ladymuir soil growth was very slow and by the time the final counts were made Morriston and Eastwood had quite outstripped Ladymuir. Moreover on Ladymuir the plants on all the treatments were almost the same size - 2" high on the average, while there was a progressive increase on the Morriston soil. (Photograph 10). The average heights were - Control $2\frac{1}{4}$"; 1 L.R., $2\frac{1}{2}$"; 4 L.R. 3". Eastwood was equal to Morriston 1 L.R. It was observed at this time that tillering had commenced on the Morriston and Eastwood soils, increasing in amount with the increase in lime.

To ensure that the plants were strong enough to withstand the disturbance due to thinning a further ten days were allowed to elapse before carrying out this operation. By then the Ladymuir plants were overcoming their period of check and were making more healthy growth. This was especially so in the case of 4 L.R. which was showing twice as much leaf growth as the others which still were equal. On the Morriston soil the same obvious increase with increased lime obtained. The most regular growth, that is the greatest uniformity of height was seen on the Eastwood soil though the plants did not thicken out to the same extent as where heavy liming had been given. While thinning was in progress the opportunity was taken to observe whether the treatments had in any way influenced the root development. It had done so in marked degree. At first it was noticed that in attempting to pull up indivudual plants by thumb and finger, those on the controls came away readily, those on 1 L.R. with difficulty and much breaking of the roots, those on 4 L.R. could not be dislodged in this manner. When plants were carefully dug up it was found that the roots on the controls were comparatively shallow with hardly any ramification. Those on 1 L.R. were deeper and more branched while on 4 L.R. the roots had penetrated still more deeply and had spread out a wide network of fibrous rootlets. (Photograph 11).

In early autumn - September - tiller counts and leaf measurements were made to determine the directions in which growth was being influenced. These are given in Table IV as averages per plant. The leaf measurements were taken from the soil level to the tips of the blades so that the two figures - number of tillers and average leaf length - taken together give an indication of the amount of growth and whether that amount is dependent mainly on elongation of stem and leaf or upon a multiplication of shoots.

TABLE IV. L. PERENNE - AYRSHIRE.

Average Number of Tillers per Plant
and Leaf Lengths. September.

Soil	Treatment	Tillers	Leaf Lengths, Inches
Morriston.....	Control	21	5
"	1 L.R.	65	9
"	4 L.R.	73	8
Ladymuir......	Control	25	7
"	1 L.R.	25.5	6.4
"	4 L.R.	42	7
Eastwood......	Nil	39	6.3

Observations and counts were made on the Kent Indigenous strain as in the case of the Ayrshire and are given below -

TABLE V. LOLIUM PERENNE - KENT INDIGENOUS.

Seedling Counts as Percentages of Seeds Sown.
Official Germination, 87%.

Soils	Morriston			Ladymuir			Eastwood
Treatments	Control	1 L.R.	4 L.R.	Control	1 L.R.	4 L.R	Nil
Days after sowing							
10	44	61	54	44	68	64	60
15	72	80	60	72	76	72	60
17	80	80	64	70	74	74	70
22	80	82	72	70	82	76	74
39	70	80	70	46	74	76	74

At the first stage the Kentish strain showed very much poorer growth all over than the Ayrshire. 1 L.R. and 4 L.R. on both Morriston and Ladymuir made growth similar to that on the corresponding controls of the Ayrshire strain. A comparison of the counts at 10 days show them to be of the same order. The seedlings on the Morriston and Ladymuir controls and on Eastwood were just appearing through the soil.

Growth proceeded regularly on the Morriston and

Eastwood soils, being greater with the additions of lime. On the Ladymuir soil the plants all remained small and on the controls were unhealthy looking, many of them beginning to wither and die soon after coming through the soil. While the plants on Ladymuir 1 L.R. and 4 L.R. were not so numerous as those of the Ayrshire strain on the corresponding soils, they were quite as healthy in appearance. At four weeks from the first count, tillering had begun on Eastwood and Morriston 1 L.R. and was proceeding strongly on Morriston 4 L.R. It had not yet commenced on Morriston controls nor on any of the Ladymuir pots. The average heights at this time were:-

Morriston	Control	2"
"	1 L.R.	2½"
"	4 L.R.	3"
Ladymuir	Control.	½"-¾"
"	1 L.R.	1½"
"	4 L.R.	2"
Eastwood		2"

A fortnight later it was necessary to thin out the plants on the Morriston and Eastwood soils. The same superior growth with increased lime was clear as before. On Eastwood the same uniformity of growth was seen as previously noted in the case of the Ayrshire strain and also as before, tillering was not taking place to the same extent as on the Morriston soil.

The root development showed the same tendency to increased depth and ramification with increased lime as did the Ayrshire strain, though not to such a marked degree.

It was impracticable to thin out the Ladymuir pots at the same time as the others owing to the plants being weaker. Indeed the controls had made no further growth for several weeks; on the contrary a considerable number of plants had died since the last count and those remaining were small and sickly. A little growth had been made on 1 L.R. which was further improved on by 4 L.R. At this time 1 L.R. and 4 L.R. were equal in development with the corresponding pots of the Ayrshire strain.

The "no lime" treatment had retarded the growth of the Kentish much more than the Ayrshire. This was most evident on Ladymuir though also quite distinct on Morriston.

Throughout the whole summer the plants on the Ladymuir controls were unable to make any headway and were left unthinned. On September 1st there were 44% of plants as compared with 46% at the last count recorded in Table V. Although counts at intermediate dates were not made, it was observed that a number of the original

46% died off during the summer so that the 44% growing in September must have been partly made up of seedlings developed from delayed germination. The tallest was a "four-leaf" plant of 3½" while the smallest was a single shoot of ½". There was of course no tillering.

TABLE VI. L. PERENNE - KENT INDIGENOUS.

Average Number of Tillers per Plant and Leaf Lengths. September.

Soil	Treatment	Tillers	Leaf Lengths Inches.
Morriston...	Control	47	7
"	1 L.R.	57	7.2
"	4 L.R.	55	8.7
Ladymuir....	Control	-	2.5
"	1 L.R.	25	8
"	4 L.R.	30	8
Eastwood....	Nil	41	7.2

DACTYLIS GLOMERATA

TABLE VII. DACTYLIS GLOMERATA - DANISH

Seedling Counts as Percentages of Seeds Sown. Official Germination, 96%.

Soils	Morriston			Ladymuir			Eastwood
Treatments	Control	1 L.R.	4 L.R.	Control	1 L.R.	4 L.R.	Nil
Days after sowing							
15	52	58	52	46	54	68	48
17	52	64	54	70	58	68	54
22	58	66	60	74	58	72	60
39	54	68	62	56	66	72	60

Ten days after sowing the seeds, shoots were beginning to appear on Ladymuir 1 L.R. and 4 L.R. but nowhere else and it was five days later before counts could be made. In the very early stages the conditions on Ladymuir seemed on the whole to be quite as suitable as on Morriston. This did not last long. A week after the first count the growth on Ladymuir slowed down while on Morriston and Eastwood it continued steadily, and at four weeks the plants were decidedly taller and stronger. Indeed by this time tillering was proceeding strongly on Morriston 4 L.R. and had just commenced on Morriston 1 L.R. and Eastwood, whereas on Ladymuir there were no signs.

On the Ladymuir controls many of the small plants were withering away. The 56% recorded in the last count (Table VII) represented living plants. A count of the dead plants made up the balance between this figure and the 74% recorded previously.

The heights of the individual plants varied considerably but the majority fell within the following limits.

Morriston, Control	-	$2\frac{1}{2}$" to 3"
Morriston, 1 L.R.	-	3" to $3\frac{1}{2}$"
Morriston, 4 L.R.	-	$3\frac{1}{2}$" to 5"
Ladymuir, Control	-	1" to $1\frac{1}{2}$"
Ladymuir, 1 L.R.	-	$1\frac{1}{2}$" to 2"
Ladymuir, 4 L.R.	-	3" to $3\frac{1}{2}$"
Eastwood	-	3" to $3\frac{1}{2}$"

It can be seen from the above figures that there was increased growth on both Morriston and Ladymuir with increased lime. In the next ten days however the difference between Morriston controls and 1 L.R. was much reduced, though 4 L.R. maintained its lead. Very little growth having taken place, the same differences as before were visible on Ladymuir.

On thinning the plants it was found that additions of lime had greatly increased the number of main roots thrown out and also the amount of fibrous rootlets. No decided difference in the depth of rooting was found

(Photograph 12).

The Ladymuir controls were not thinned owing to the weakness of the growth. Almost all the plants, however, struggled on and by September the number was the same as at the final seedling count. Much variation in the sizes was seen, the range being from 8" down to 2" with an average of 4". Even in the tallest plants tillering had not commenced.

TABLE VIII. DACTYLIS GLOMERATA - DANISH.

Average Number of Tillers per Plant and Leaf Lengths. September,

Soil	Treatment	Tillers	Leaf Lengths Inches.
Morriston....	Control	4.5	13
"	1 L.R.	5.6	11
"	4 L.R.	3.6	11.5
Ladymuir.....	Control	-	4
"	1 L.R.	4	12
"	4 L.R.	4.8	11.2
Eastwood.....	Nil	3.3	7

TABLE/

TABLE IX. DACTYLIS GLOMERATA - NEW ZEALAND.

Seedling Counts as Percentages of Seeds Sown. Official Germination 88%.

Soils	Morriston			Ladymuir			Eastwood
Treatments	Control	1 L.R.	4 L.R.	Control	1 L.R.	4 L.R.	Nil
Days after sowing							
15	40	34	30	40	38	28	24
17	34	34	36	46	44	34	30
22	61	60	64	58	60	62	44
39	58	62	64	58	70	72	48

In spite of the greater number of seedlings produced on Ladymuir than on the other soils, growth there was very slow and the plants were not so healthy as on Morriston and Eastwood. Of the 58% recorded at the last count on Ladymuir only 5% did not show some yellowing and withering of the leaves. A few plants were also affected on Ladymuir 1 L.R. but on 4 L.R. and all on Morriston and Eastwood were quite healthy though of varying sizes. At this time also, tillering had commenced on Eastwood and Morriston and was progressive in extent with the increase in lime. There was no tillering on Ladymuir. The heights of the plants were -

Morriston, Control	-	2" to 2½"
" 1 L.R.	-	2½" to 3"
" 4 L.R.	-	3½" to 4"
Ladymuir, Control	-	½"
" 1 L.R.	-	¾"
" 4 L.R.	-	1" to 1½"
Eastwood	-	3"

A fortnight later it was possible to thin out the plants on Morriston and Eastwood. They were all healthy. Morriston, controls and 1 L.R. and Eastwood showed equal growth, but 4 L.R. was taller and thicker. Ladymuir could not be thinned at this time as the growth on the controls and 1 L.R. was still poor and stunted with the exception of very occasional plants on 1 L.R. On 4 L.R. all were taller and healthier.

On removal of the surplus plants very little difference in the rooting systems could be seen except a slightly greater fibrous development in the case of 4 L.R.

In three weeks time it was necessary to thin out Ladymuir 1 L.R. and 4 L.R. The plants on these were all healthy and strong with slightly more growth on 4 L.R. which however was only half the height, though more spreading and tillered, than the Danish strain on the corresponding soil and treatment. Ladymuir Control was still very small and making hardly any growth. Like those of the Danish strain, however, they persisted and by early autumn the same number as previously noted still survived. Growth was very irregular. The plants ranged from 7½" to ½" high with an average of only 4½" with no evidence of tillering even in the tallest. The other data for this time are given below.

TABLE X. DACTYLIS GLOMERATA - NEW ZEALAND.

Average Number of Tillers per Plant and Leaf Lengths. September,

Soil	Treatment	Tillers	Leaf Length Inches
Morriston...	Control	6.6	9.8
"	1 L.R.	9	7
"	4 L.R.	9.6	7.9
Ladymuir....	Control	-	4.5
"	1 L.R.	5	7.5
"	4 L.R.	10.3	10
Eastwood....	Nil	10	7.5

TABLE/

Photograph 13.

Dactylis glomerata Welsh. July. Back, Ladymuir soil, left to right; Control, 1 L.R., 4 L.R. Centre, Morriston soil, left to right; Control, 1 L.R., 4 L.R. Front; Eastwood soil.

Photograph 14.

Phleum pratense - Scotch. Morriston soil, July. Left; Control. right; 4 L.R.

Photograph 15.

Phleum pratense - Welsh, Morriston soil. July. Left; Control. Right; 4 L.R.

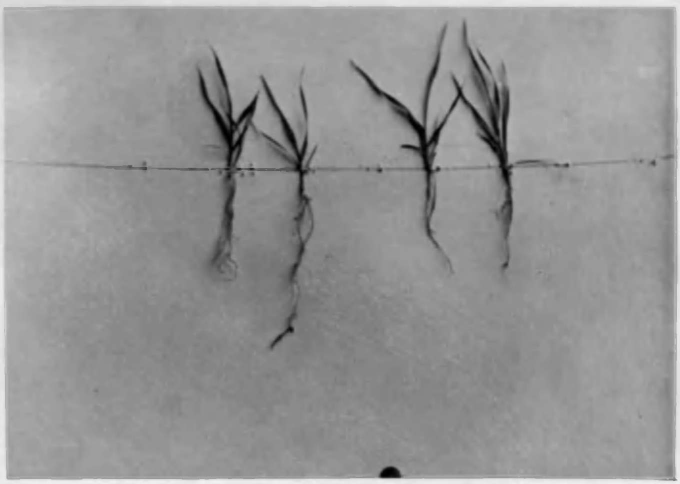


TABLE XI. DACTYLIS GLOMERATA - WELSH

Seedling Counts as Percentages of Seeds Sown. Official Germination, 90%.

Soil	Morriston			Ladymuir			Eastwood
Treatments	Control	1 L.R.	4 L.R.	Control	1 L.R.	4 L.R.	Nil
Days after sowing							
15	20	40	40	18	50	28	26
17	24	46	48	18	54	40	38
22	52	64	78	34	70	54	60
39	56	76	78	42	76	58	60

Here, as in the case of the New Zealand strain the early growth was much better on Morriston and Eastwood than on Ladymuir. At the time of the last count there was a definite increase in growth with the increase of lime, though the difference between the controls and 1 L.R. was not so great as between 1 L.R. and 4 L.R. (Photograph 13). During the following few weeks the differences between Eastwood, Morriston control and Morriston 1 L.R. tended to disappear while the difference between these and 4 L.R. became more accentuated. This advantage appeared to be partially lost in the next three weeks. The heights and general behaviour were much like those of the New Zealand strain.

The final count of 42% on Ladymuir controls gives an exaggerated idea of the amount of growth for every plant was small, stunted and showing signs of withering. On 1 L.R. they were slightly bigger (1" to 1½") and healthier though a number showed traces of yellowing. All the plants on 4 L.R. were larger (1½" to 1¾") and quite healthy with every appearance of ultimately developing into mature plants. The few weeks following saw very slight growth on the controls, but 1 L.R. improved a little. A large increase was noted on 4 L.R. While growth was very like that on the corresponding New Zealand pots the plants were slightly taller and did not tiller quite so freely and there was a clearer increase with additional lime.

The plants on Ladymuir controls remaining small, were left unthinned and when counted at the beginning of September it was found that the numbers had increased to 52% as compared with the previous 42%. As usual, growth on the controls with this soil was very irregular there being a range from plants of 6" just beginning to tiller, down to seedlings of 1".

TABLE/

TABLE XII. DACTYLIS GLOMERATA - WELSH.

Average Number of Tillers per Plant and Leaf Lengths. September.

Soil	Treatment	Tillers	Leaf Length Inches.
Morriston...	Control	9	6.5
"	1 L.R.	10.5	6.5
"	4 L.R.	8	8.5
Ladymuir....	Control	-	3
"	1 L.R.	3.6	6
"	4 L.R.	12.6	10
Eastwood....	Nil	11	6.2

PHLEUM PRATENSE

TABLE XIII. PHLEUM PRATENSE - SCOTCH

Seedling Counts as Percentages of Seeds Sown. Official Germination, 85%.

Soils	Morriston			Ladymuir			Eastwood
Treatments	Control	1 L.R.	4 L.R.	Control	1 L.R.	4 L.R.	Nil
Days after sowing							
15	40	70	62	34	62	70	58
17	50	80	70	42	66	84	64
22	72	80	82	42	68	84	68
39	80	82	84	38	70	81	68

From the beginning, the plants on Morriston grew on steadily, showing a progressively stronger growth with increase of lime. This increase was more pronounced than the final seedling counts would indicate. The plants on Ladymuir controls remained small and sickly. On Ladymuir 1 L.R. and 4 L.R. the plants were small compared with those on Morriston but were quite healthy in appearance. The heights at this stage were -

Morriston, Control - 1½" to 2"
Morriston, 1 L.R. - 3½" to 4"
Morriston, 4 L.R. - 4" to 5"
Ladymuir, Control - ¾" to ½"
Ladymuir, 1 L.R. & 4 L.R. - 1¼" to 1½"
Eastwood - 2½" to 3"

A week later the plants on all pots except the Ladymuir controls were thinned. There was óver all a tendency to increased growth with increase of lime. The growth was most regular on Eastwood. Rooting was found to be deeper and with a slightly greater spread of fibrous rootlets on the controls than where lime had been added to the soil. (Photograph 14).

In a further two weeks Morriston 4 L.R. reached its maximum growth for the season and commenced to produce ears which soon came into flower: this was closely followed by 1 L.R. It was sixteen days later when the first ear emerged from the controls. Eastwood came into ear six days after Morriston 1 L.R. During this time Ladymuir controls remained feeble but ultimately a few plants began to make more healthy growth. The limed pots grew much better, growth being most vigorous on 4 L.R.

By early autumn the 38% recorded at the last count on Ladymuir control was reduced to 24% and only one plant showed the commencement of tillering.

The tillering and leaf lengths at this time are given in Table XIV.

TABLE/

TABLE XIV. PHLEUM PRATENSE - SCOTCH

Average Number of Tillers per Plant and Leaf Lengths. September.

Soil	Treatment	Tillers	Leaf Lengths Inches.
Morriston....	Control	7	12
"	1 L.R.	12	14
"	4 L.R.	8.3	10
Ladymuir.....	Control	-	3.5
"	1 L.R.	6	8
"	4 L.R.	7	13
Eastwood.....	Nil	10.6	12

TABLE XV. PHLEUM PRATENSE - WELSH

Seedling Counts as Percentages of Seeds Sown. Official Germination, 84%.

Soils	Morriston			Ladymuir			Eastwood
Treatments	Control	1 L.R.	4 L.R.	Control	1 L.R.	4 L.R.	Nil
Days after sowing							
15	14	16	30	12	34	36	34
17	36	36	42	28	40	54	44
22	42	42	44	44	52	54	50
39	40	42	48	52	58	70	50

As a whole growth was slower with this strain than the Scotch and the plants suffered more in the early stages - particularly on Ladymuir - from want of lime. At the date of the last count the heights were -

Morriston, Control - $1\frac{1}{4}$" to $1\frac{1}{2}$"
Morriston, 1 L.R. & 4 L.R. - 2" to $2\frac{1}{2}$"
Ladymuir, Control - $\frac{1}{2}$" to $\frac{3}{4}$"
Ladymuir, 1 L.R. & 4 L.R. - $\frac{3}{4}$" to 1"
Eastwood - 2" to $2\frac{1}{4}$"

In the following weeks, growth was continuous on Morriston, becoming more abundant with increasing lime. Root development however was not so great (Photograph 15). Four weeks after the final count 4 L.R. "came into ear", with 1 L.R. four days later.

Growth continued to be very slow on Ladymuir and it was fully six weeks after the last count before 1 L.R. and 4 L.R. became really vigorous. The heights at this time were $4\frac{1}{2}$" and $6\frac{1}{2}$" respectively. The controls had failed to make any advance in growth and mortality was high. By the beginning of September, instead of 52% there was only 11%.

TABLE XVI. PHLEUM PRATENSE - WELSH

Average Number of Tillers per Plant and Leaf Lengths. September.

Soil	Treatment	Tillers	Leaf Lengths Inches
Morriston....	Control	9.6	5
"	1 L.R.	15	7.5
"	4 L.R.	20.3	7.2
Ladymuir.....	Control	-	3
"	1 L.R.	3.7	5
"	4 L.R.	4.6	6.7
Eastwood.....	Nil	18	7.5

Photograph 16.

Phleum pratense - Gloria. July. Back, Morriston soil, left to right; Control, 1 L.R., 4 L.R. Front; Eastwood soil.

Photograph 17.

Section of Pot Experiment Series II. Left; Eastwood soil. Centre; Morriston soil. Right; Ladymuir soil.

TABLE XVII. PHLEUM PRATENSE - GLORIA.

Seedling Counts as Percentages of Seeds Sown. Official Germination, 80%

Soils	Morriston			Ladymuir			Eastwood
Treatments	Control	1 L.R.	4 L.R.	Control	1 L.R.	4 L.R.	Nil
Days after Sowing							
15	36	40	40	16	58	72	60
17	58	62	64	42	74	80	70
22	64	70	68	46	80	80	74
39	70	72	72	50	78	80	76

From the beginning, the growth on Morriston was strong and rapid while that on Ladymuir - particularly the controls - was very slow. At ten days before the final count the heights of the plants were -

Morriston, Control - $2\frac{1}{2}$" to 3"
Morriston, 1 L.R. - 3" to 4"
Morriston, 4 L.R. - 4" to 5"
Ladymuir, Control - $\frac{1}{8}$" to $\frac{1}{4}$"
Ladymuir, 1 L.R. & 4 L.R. - $\frac{1}{2}$" to $\frac{3}{4}$"
Eastwood - 3" to $3\frac{1}{4}$"

Growth on Morriston continued steadily, being stronger with increased lime. (Photograph 16). Four weeks after the final count 4 L.R. came into ear with 1 L.R. four days later.

In the fortnight following the final count the majority of the seedlings on Ladymuir controls died off leaving only a few sickly survivors, which all succumbed during the next two weeks leaving the controls completely blank. On 1 L.R. and 4 L.R. there were some casualities but the majority of the plants remained healthy and though growth was slow, 4 L.R. showed a decided increase over 1 L.R. The growth on Eastwood was as usual the most regular and in amount almost the same as Morriston 1 L.R.

The tendency to restricted root development with increase in the lime content of the soil was not observed in the case of this strain.

By September the count on Ladymuir 1 L.R. was reduced from 78% to 64%; and on 4 L.R. from 80% to 68%. On the former there was no sign of tillering while on the latter it was just beginning on a few of the more vigorous plants. The other data for this time are given in Table XVIII.

TABLE/

TABLE XVIII. PHLEUM PRATENSE - GLORIA.

Average Number of Tillers per Plant and Leaf Lengths. September.

Soil	Treatment	Tillers	Leaf Lengths Inches.
Morriston....	Control	5.2	7.5
"	1 L.R.	5.5	7.5
"	4 L.R.	6	8
Ladymuir.....	Control	-	-
"	1 L.R.	-	5
"	4 L.R.	-	5
Eastwood.....	Nil	3	5

ALOPECURUS PRATENSIS.

TABLE XIX. ALOPECURUS PRATENSIS.

Seedling Counts as Percentages of Seeds Sown. Official Germination, 73%.

Soil	Morriston			Ladymuir			Eastwood
Treatment	Control	1 L.R.	4 L.R.	Control	1 L.R.	4 L.R.	Nil
Days after sowing							
12	16	6	2	-	4	6	4
15	30	30	18	4	22	18	24
21	40	40	30	8	22	22	32
37	44	44	46	8	18	24	36

The plants on Morriston and Eastwood soils all grew satisfactorily from the beginning. No differences were observable at the time of the last count, but during the next three weeks 4 L.R. grew a little faster than the others, leaving Morriston controls, 1 L.R. and Eastwood equal. The seedlings that did appear in Ladymuir were very small and weak and gave little promise of surviving. In spite of this a fair number did persist and by September there were 14% on 1 L.R. and 18% on 4 L.R. as compared with 18% and 24% previously recorded. During the summer the plants on the controls gradually died off till by autumn none were left. The position at this time is shown in Table XX.

TABLE XX. ALOPECURUS PRATENSIS

Average Number of Tillers per Plant and Leaf Lengths. September.

Soil	Treatment	Tillers	Leaf Length Inches
Morriston....	Control	5.5	7
"	1 L.R.	13	9
"	4 L.R.	16.6	9.6
Ladymuir.....	Control	-	-
"	1 L.R.	-	2
"	4 L.R.	-	2
Eastwood.....	Nil	10	7.8

POA TRIVIALIS

TABLE XXI. POA TRIVIALIS

Seedling Counts as Percentages of Seeds Sown. Official Germination 91%.

Soil	Morriston			Ladymuir			Eastwood
Treatment	Control	1 L.R.	4 L.R.	Control	1 L.R.	4 L.R.	Nil
Days after sowing							
15	60	60	50	14	50	34	44
21	70	70	74	36	62	50	66
37	70	71	73	4	56	54	66

Up to 12 days after sowing, no appearance was made by this grass so that three days later, when the first counts were possible, the seedlings were very small, When growth did begin, maximum numbers were quickly reached and thereafter in some cases they tended to fall off.

By the date of the last count tillering had commenced on all the Morriston and Eastwood pots and was progressive with increased lime. The heights of the plants at this time were -

Morriston,	Control	-	2" to 3"
"	1 L.R.	-	3" to 4"
"	4 L.R.	-	4" to 4½"
Eastwood		-	2½" to 3"

All the shoots on the Ladymuir soil were much smaller than any of these on Morriston or Eastwood noted above and had a stunted, unhealthy appearance.

During the next month all the plants on Ladymuir controls died off. About a fifth of those on 1 L.R. and 4 L.R. died while the survivors grew very slowly. In this period the Morriston controls overtook 1 L.R. but 4 L.R. maintained its lead. Eastwood showed growth equal to Morriston 1 L.R. and was the most regular of any.

By September there were on Ladymuir 1 L.R. and 4 L.R., 44% and 42% of plants respectively as against the previous 56% and 54%. About half of the plants had commenced to tiller, the others were still in the seedling stage. Table XXII gives the details at this time.

TABLE XXII. POA TRIVIALIS.

Average Number of Tillers per Plant and Leaf Lengths. September.

Soil	Treatment	Tillers	Leaf Length Inches
Morriston...	Control	18.5	4.2
"	1 L.R.	22.6	4.0
"	4 L.R.	28.4	5.5
Ladymuir....	Control	-	-
"	1 L.R.	2.7	3.5
"	4 L.R.	3.2	3.7
Eastwood....	Nil	13.6	3.6

POT EXPERIMENTS - SERIES III.

In previous trials the maximum amount of calcium carbonate applied was approximately 4% of the weight of the soil. The growth from such treatment, while in some cases little if any better than that obtained from a quarter of that amount of lime, never showed decidedly adverse effects. As no information was available as to the amount of lime which grasses could tolerate and remain healthy it was resolved to test the effects of very large amounts.

PROCEDURE and OBSERVATIONS

Owing to limitations to space it was only possible to use three grasses and in view of their increasing importance the indigenous strains were selected. These were -

Lolium perenne	-	Kentish
Dactylis glomerata	-	Welsh
Phleum pratense	-	Welsh

The soil in which these were grown was that referred to previously as "Eastwood" - a clay loam. This soil was chosen because it showed no deficiency in lime (Lime requirement, 0.042% $CaCO_3$) and therefore none of the lime applied was required to counteract an initial acidity, but was entirely available to exert any "excess" influence which might arise.

To five portions of soil, calcium carbonate was added at the rates of 5%, 10%, 20%, 40% and 80% of the weight of soil. The lime was thoroughly incorporated with each portion of soil and the mixtures potted. Each pot was then saturated with water and allowed to dry several times before planting the grass seeds at the end of May.

Seedling counts were made at a fortnight and a month after planting and are given in Table XXIII as percentages of the seeds sown.

TABLE XXIII. Seedlings on Soil receiving Heavy Increments of $CaCO_3$. Counts as Percentages of Seeds Sown.

Days after Sowing	Species	Official Germination %	$CaCO_3$ as Percentage of Weight of Soil.				
			5%	10%	20%	40%	80%
14	L.perenne	87	80	74	74	58	72
28	L.perenne	87	80	76	70	80	70
14	Phleum. prat.	84	66	64	64	52	52
28	Phleum. prat.	84	70	62	62	64	58
14	Dactylis glom.	90	38	40	30	34	20
28	Dactylis glom.	90	72	60	50	62	64

L.perenne. At the time of the first count all the seedlings were quite healthy though those on the 80% lime treatment were slightly stronger than the others. The ranges of heights then were:- 80% lime treatment, 1" to 1½"; all others ½" to 1". At the second count all were still quite vigorous. On the 5% lime treatment the heights were from 2½" to 3½". On the other treatments the heights were slightly greater - 4" to 4½" - but did not vary appreciably among themselves.

As the season proceeded a change began to take place. From the beginning of August growth began to slow down on the 20%, 40% and 80% treatments and by the middle of the month growth had ceased. Thereafter the plants began to yellow and many leaves died off in early autumn. The height of the plants was 4½" to 5½". The 5% and 10% treatments on the other hand did not seem to inconvenience the plants at all. On the contrary growth was much better on these than on the same soil receiving no treatment, and continued green and vigorous right into winter. The average autumn heights were - 5% treatment, 6¾"; 10% treatment 7½".

<u>Phleum pratense</u>. Fourteen days after sowing, at the first seedling count, the plants were seen to be progressively smaller with the increased applications of lime. On the 5% lime treatment the heights were from ¼" to ½" while on the 80% lime treatment the tips of the shoots

were just visible emerging from the soil. A fortnight later the plants on all treatments up to and including 40% lime were approximately of equal height - 2" to $2\frac{1}{4}$" - while those on the 80% treatment were much smaller - only about $\frac{1}{2}$".

Subsequent growth was never quite so abundant from any treatment in this experiment as when the plants were grown on the untreated soil. At 5%, 10% and 20% the differences were very slight; thereafter the plants became a little smaller and appeared stunted. At all the treatments, the leaves tended to wither and burn in winter more readily than when no treatment had been given.

Dactylis glomerata. The first count could only be made with difficulty as at this time the tips were just making an irregular appearance through the soil. In a further fortnight however all the plants were from 2" to $2\frac{1}{2}$" high and all apparently quite healthy. Tillering was commencing on the 5% and 10% lime treatments but not on the others.

Growth and development at later stages was very inconsistent. At 5%, 20% and 80% the plants remained small and the leaves were pale, while at 10% and 40% the plants were much stronger and a darker green.

DISCUSSION of RESULTS from POT EXPERIMENTS

LOLIUM PERENNE

The first point emerging from the investigations on this grass is the certainty of the benefit which it derives from having the soil acidity counteracted by the addition of lime. In the first series of experiments the plants - similar to those designated "Ayrshire" in Series II -when grown on acid soil were always small and rather delicate with apparently little reserve strength to survive temporary adverse conditions such as frost and drought. This lack of vigour did not prove to be a passing phase but tended to become more accentuated with time and it seemed probable that had it been possible to continue the trial long enough all or at least a large majority of the plants would have died off. On the other hand in the presence of lime the plants were as strong and luxuriant as could be desired and gave every evidence of ability to survive indefinitely.

In Series II where the behaviour of this grass was studied in much greater detail, the advantages accruing from the liming of acid soils were confirmed.

The germination of the seeds of the Ayrshire strain as officially guaranteed was 91% but it is clear from the counts of the seedlings that this figure gives little idea of the number of plants likely to establish themselves unless the acidity of the soil has been effectively checked by heavy liming. Where this was done by applying lime at the lime requirement rate the seedlings surviving 39 days after the sowing were 86 per 100 seeds sown on both sandy and peaty soil; on clay loam where the test showed no lime requirement the number was 88. When, however, four times the lime requirement was applied to the sandy and peaty soils the numbers rose to 92 and 94 respectively. With the exception of the earlier counts on the clay loam, these were the only occasions throughout the series of experiments where the number of plants exceeded the official germination figure.

When the plants on the acid unlimed soils are considered it is found that the highest counts obtained were 82 on the sandy soil and 78 on the peaty soil at 17 days after sowing. All the plants did not survive, however, and at 39 days these were reduced to 64 and 72.

The Kent Indigenous strain behaved somewhat differently. The official germination here was 87%, while the plants per 100 seeds at 39 days on the sandy and peaty soils receiving the one lime requirement application numbered 80 and 74; and on the neutral clay loam,

74. By increasing the lime up to four times the lime requirement the numbers were not raised to that of the official germination as with the Ayrshire strain but were depressed on the sandy soil and hardly influenced on the humus soil. Moreover, on the clay loam, increments of lime up to 80% by weight of the soil failed to affect appreciably the number of seedlings which varied between 70 and 80. On the untreated acid soils the numbers were low - 70 and 46 as compared with the 80 and 74 mentioned above. Making the comparison in another way - if it be assumed that the official germination figure represents the maximum number of plants which could possibly be obtained, then the Ayrshire strain gave 70.3% of the possible on the untreated sandy soil and 79.1% on the peaty soil at 39 days from sowing. When the soils were treated at the lime requirement rates 94.5% of the possible was obtained in both cases. That is, an increase of 24.2% on the sandy soil and 15.4% on the peaty soil. With the Kent Indigenous strain the numbers on the untreated soils were 80.5% and 52.8% of the possible, whereas when the soils received their lime requirements the numbers were 91.9% and 85.0%, or an increase on the sandy of 11.4% and 32.2% on the peaty soil. It appears from these

figures and those in Tables III and V that in addition to the slightly greater viability of the Ayrshire seeds as indicated by the germination test, they also have the power of producing a greater number of healthy seedlings per hundred viable seeds than have those of the Kentish strain. Further, while the Ayrshire strain responded much better to the one lime requirement treatment on the sandy soil than the Kentish (24.2% against 11.4%), and the Kentish better than the Ayrshire on the peaty soil (32.2% against 15.4%) the response to the four lime requirement treatment on both soils was entirely to the advantage of the Ayrshire strain. Thus, on these bases of reckoning, the Ayrshire strain in its early stages seems on the whole to be decidedly more responsive to the influence of lime, or conversely to have its potentiality for the production of a high percentage of healthy young plants more repressed by severe soil acidity, than the Kentish strain.

The fact of fewer seedlings being found, after five or six weeks from sowing the seed, on untreated acid soil than where lime was applied, was apparently due partly to the failure of the seeds to germinate at all - or at least to produce a shoot long enough to reach the soil surface - and partly to seedlings dying between three and five weeks from the time of sowing. This mortality among the seedlings was the more important cause of the small number of healthy maturing plants compared with the number of seeds sown. The dying of the seedlings was not entirely confined to the untreated soils but was much more prevalent there than where lime had been given.

Although, as already mentioned, the Ayrshire strain suffered more by the acid soil conditions, from the point of view of numbers of seedlings, than the Kentish, the latter suffered more, especially on the peaty soil, during the subsequent developmental period. On the peaty soil both strains experienced difficulty in emerging from the seedling stage and becoming established plants. It took the Ayrshire strain fully six weeks from the first appearance of the seedlings above ground to overcome this period of arrested growth and proceed normally. On the other hand the tallest plant which the Kentish could produce after three months was only $3\frac{1}{2}$ inches high and the majority were considerably smaller. In addition to having retarded growth, the conditions of the acid peaty soil seemed to have delayed germination to some extent though the number of new plants arising from seeds activated later was just sufficient to replace casualities among the previously existing seedlings.

On the acid sandy soil the Kentish seemed for a time to be more adversely affected than the Ayrshire but only transitorily.

Tillering was commenced by both strains between five and six weeks from sowing the seed. It began first on the sandy soil, with the four lime requirement treatment, then on the same soil with the one lime requirement and on the neutral clay loam. On the untreated sand the Ayrshire was earlier than the Kentish. It was some time later before there was any tillering on the peaty soil and there, as on the sand, it was most profuse under the high rate of liming. In the early autumn when actual counts of the tillers were made it was noticeable that for the most part where tillering had begun earliest it was most abundant. In all cases the four lime requirement treatment gave the greatest average number of tillers except in the case of the Kentish strain on the sandy soil where the number was almost the same as on the one lime requirement; and in all cases except the Ayrshire strain on the peaty soil there was a large increase on the one lime requirement over the controls. Indeed up to the time of counting, the Kent Indigenous had failed to produce any tillers on the untreated peaty soil. The indications are therefore, as far as tillering is concerned, that on acid sandy soil the Ayrshire strain responds much better to additions of lime than the Kentish, while on peaty soil the reverse is the case, but while the Kentish gives little additional response to raising the lime content of either sandy or peaty soil from its lime requirement to four times that amount, the Ayrshire does give an increase. The latter, however, apparently demands more lime than the theoretical requirement to induce increased tillering on peaty soil.

The number of tillers alone is not always a true indication of the amount of growth which has been made, but if tillers and average leaf length be taken together then a good idea of the relative amount of total growth can be obtained. If the average number of tillers be multiplied by the average number of inches of leaf length, and the product divided by 100 - to give easily handled figures and eliminate small differences - an Index of Growth is obtained for each case. A comparison of the Indexes in Table XXIV enables the grasses on the different soils and treatments to be placed in the same relative positions as would be done by actual observation.

TABLE/

TABLE XXIV. LOLIUM PERENNE. INDEXES of GROWTH.

Soil	Treatment	Ayrshire	Kent Indigenous
Sandy	Control	1.0	3.3
"	1 L.R.	5.8	4.1
"	4 L.R.	5.8	4.8
Peaty	Control	1.7	-
"	1 L.R.	1.6	2.0
"	4 L.R.	2.9	3.2
Clay loam	Nil	2.4	2.9

It will be seen from the above table that the position from the aspect of total growth is not quite the same as when considering tillers only. The Ayrshire strain responded more to treatment on the sandy soil than the Kentish; and the Kentish more on the peaty soil than the Ayrshire - since the former gave no tillering on the untreated soil. This is in agreement with the tiller counts alone. But whereas the number of tillers of the Kentish strain did not increase appreciably with the further addition of lime and that of the Ayrshire did, the increased leaf length of the Kentish tended to increase the growth as a whole on the sandy soil. The additional growth however was not great, the increase in the Index being only 0.7. On the peaty soil the increase in the Index was practically the same for both strains, 1.3 for the Ayrshire and 1.2 for the Kentish.

It is noteworthy that on the neutral clay loam the number of tillers of both strains fell between those on the peaty and sandy soils receiving the one lime requirement treatment, being higher than on the former and lower than on the latter. The amounts of growth occupied the same relative positions and never exceeded that on either soil receiving four times the lime requirement. On this soil the Kentish strain benefited by increments of lime up to 10% by weight of the soil. At higher rates growth was diminished.

DACTYLIS GLOMERATA.

The growth of Dactylis on various acid soils, untreated and treated with lime has brought out some interesting facts. The strain used in Series I was the same as that referred to as "Danish" in Series II, while the soil, though not exactly the same as either the sandy or the peaty soil of Series II tended much more in character to that of the latter than the former. It was therefore on the peaty soil of the second series that the behaviour most closely resembled that of the first series.

Confirmation was obtained of the earlier observations that while yet in the seedling stages much benefit was obtained by the plants from the addition of lime to an acid soil containing a high organic matter content. The benefit did not cease with the application of lime at the theoretical requirement rate but was continued to at least twice that rate. In point of fact it was continued to four times the lime requirement rate on the soil with the higher organic content. Nor was the increased growth and vigour confined to the seedling stage but continued thereafter for the duration of the trials - in the first series for three years.

On sandy soil as on the peaty, greater numbers and larger plants resulted from giving the soil its lime requirement. Whether the numbers and size would have been further increased by twice the lime requirement the experiment did not show, but four times the requirement gave larger plants but smaller numbers. After a year's growth these plants were still slightly taller than those receiving the one lime requirement but were less profusely tillered - even less than those receiving no lime - so that their total amount of growth was considerably less.

The official germination of the Danish seed was 96% but at no time did the number of seedlings come within twenty of that figure. At 39 days after sowing the seeds there were only 54 plants per 100 seeds sown on the untreated sandy soil, and 56 on the peaty soil. Where the lime requirements had been supplied the numbers rose to 68 and 66, while on the neutral clay loam there were 60. With the lime raised to four times the requirements the number was further increased on the peaty soil to 72 but on the sand was depressed to 62. The New Zealand strain with a lower germination figure - 88% produced quite as many plants as the Danish. On the untreated soils 58 plants per 100 seeds were present on each, 39 days after sowing. This was increased on the sandy soil to 62 and on the peaty to 70 when the lime requirement was given. On the neutral clay loam there were only 48. With four times the lime requirement the figures rose to 64 and 72. The germination of the Welsh strain was 90%. Counts at the same date as for the others showed 56 plants on the sandy soil and 42 on the peaty. These both rose to 76 at the one lime requirement rate. At four times that rate, 78 plants were recorded on the sand; on the peat there was a fall to 58. On the clay loam the number was 60.

From these data it is seen that by the addition of lime to the sandy soil at the lime requirement rate the number of seedlings surviving 39 days after sowing or approximately 4 weeks after germination commenced, increased for each of the three strains tested. The Danish strain rose by 14 per 100 seeds, the New Zealand by 4 only and the Welsh by 20. The increase of lime to four times the requirement rate resulted in a decrease by the Danish of 4, and an increase by the New Zealand and Welsh of 2 each over the numbers from the one lime requirement rate. It is therefore evident that from the point of view of numbers of seedlings, while the Danish and the Welsh benefit on this soil from the requirement rate of liming there is nothing to be gained by further heavy additions. On the other hand the New Zealand strain does not appear to be markedly influenced by either moderate or heavy applications.

On the peaty soil the lime requirement raised the Danish by 10, the New Zealand by 12, and the Welsh by 34. Four times the lime requirement further increased the Danish by 6 and the New Zealand by 2 but depressed the Welsh by 18. On this soil then, the first rate of liming is of decided benefit, especially to the Welsh strain but the higher rate was of material advantage only to the Danish.

As reflected by number of seedlings the Welsh strain is the most sensitive to additions of lime at the requirement rate on both sandy and peaty soils but on the latter, very heavy rates apparently reduce the numbers.

The Danish strain, it may be noted, was the only one to show any tendency for the seedlings to die at an early age and this only on the untreated acid soils. On the sandy soil the numbers as percentages of the seeds sown fell from 58 at 22 days after sowing to 54 at 39 days; on the peaty soil from 74 to 56. Thus the smallness of the number of plants surviving was due not entirely to the seeds failing to produce plants but partly to the inability of the seedlings to survive on the acid soil.

It is generally accepted that Dactylis is better adapted to "light" than to "heavy" soil thus the seedling counts on the clay loam compared with those on the sandy and peaty soils are interesting. The clay loam showed practically no lime requirement and had a high pH value (6.45) therefore the question of acidity between it and the soils treated at the lime requirement rate hardly arises. If there were anything in it, the treated soils might have been slightly more acid than the clay loam as the saturating process possibly might have been proceeding still at this time. In every case the numbers on the sand and peat exceeded those on the clay loam. The Danish strain showed the smallest increases, being 8 per 100 seeds on the sand and 6 on the peaty soil; those for the New Zealand were 14 and 22; for the Welsh 16 and 16. From this it appears that at least part of the unsatisfactory response of Dactylis on clayey soils is due to poor germination.

Since the germinating capacity of the seeds of the strains varies, the same device may be employed as in the case of Lolium to eliminate the differences in percentage germination and show the number of seedlings as percentages of the possible number of plants which might be produced - the official germination percentage being taken as the maximum possible. This has been done with the results shown in Table XXV.

TABLE XXV. DACTYLIS GLOMERATA.

Percentages of Possible Number of Plants at 39 Days after Sowing Seed.

Soil	Treatment	Danish	New Zealand	Welsh
Sandy	Control	56.2	65.9	62.2
"	1 L.R.	70.8	70.4	84.4
"	4 L.R.	64.6	72.7	86.6
Peaty	Control	58.3	65.9	46.6
"	1 L.R.	68.7	79.5	84.4
"	4 L.R.	75.0	81.8	64.4
Clay loam	Nil	62.5	54.5	66.6
Average		65.1	70.1	70.7
Official Germination		96%	88%	90%

Contrary to the findings in the case of Lolium the above figures reveal that for this species the strain with the highest germinating capacity under the official test gave the lowest percentages of possible plants, the Danish giving on the average 5% less than either the New Zealand or the Welsh. It is interesting to note how nearly alike are the average numbers for these two strains, - 70.1% and 70.7%.

The differences in numbers of actual plants were sufficiently great to leave the relative positions practically unchanged when recalculated on the basis of viability. Thus the previous remarks hold also for the percentages of possible number of plants produced. It is, however, noteworthy that while for the Danish and New Zealand strains, the highest number of surviving plants of each was 72 per 100 seeds (on Peaty soil, 4 L.R.) when calculated as percentages of the possible the former produced only 75.0 but the latter 81.8. The highest percentage of the possible over all (86.6) was recorded by the Welsh strain on the sandy soil receiving four times its lime requirement. This however was only 2.2 better than where the bare lime requirement was given on either the sandy or the peaty soil.

The lowest percentage of the possible (46.6) was given by the same strain on the untreated peaty soil, thus the remarkable increase of 37.8% was obtained from the one lime requirement treatment.

The previous remarks have been made in respect of seedling numbers, and it may have been noticed that the numbers on the peaty soil where quite as large as on the sandy soil. Subsequent growth however showed that the plants of all strains had much greater difficulty in developing on the peaty than on the sandy soil. This was particularly so where no treatment was given. So weak indeed was the growth on the peaty soil that thinning was unnecessary as there was no danger of crowding. Moreover in no case did tillering take place even feebly during the whole period of test. Where this soil was supplied with lime however, although growth was somewhat checked in the early stages, the plants progressed vigorously later in the season particularly where four times the lime requirement was given and in some cases they surpassed those growing on the sandy soil.

In every instance growth was stronger in the early stages on the sandy and clay loam soils than in the peaty. This was most pronounced with the Danish strain, but with all strains on both acid soils there were distinct increments of growth with increased application of lime. The amount of growth on the neutral loam was similar to that on the sandy soil receiving its lime requirement.

The added lime had quite a noticeable influence on the tillering. This was seen to commence first on the soils most heavily limed and to occur in order as the lime content decreased. On the sandy soil this development took place earlier than on the peat.

Tiller counts made on the plants in situ during early autumn showed that the early commencement on the heavily limed sandy soil had not given any continued advantage. In fact the Danish and Welsh strains had a smaller average number of tillers there than where either no treatment or one lime requirement was given. On the peaty soil, however this was not so. As already indicated there was no tillering on the controls but the increase from the four over the one lime requirement was very large for the New Zealand and Welsh strains and slight for the Danish. The average increases per plant were - New Zealand 5.3, Welsh 9.0, Danish 0.8.

There was an increase in each case on the sandy soil receiving one lime requirement compared to the untreated soil but it was never great. For the Danish it was 1.1, for New Zealand 2.4, for Welsh 1.5.

Although the average numbers of tillers on the peaty soil receiving the lime requirement were not great in themselves it must be considered that this rate of liming is very effective in increasing tillering since without lime no tillering took place at all.

On the clay loam, though the numbers of seedlings had been lower than on the corresponding sandy and peaty soils, subsequent growth - the height of the plants was almost the same as on the sandy soil treated at the one lime requirement rate, and rather better than on the peaty soil. The tiller counts in early autumn were in approximately the same relative order except for the Danish strain which was 2.3 less than on the sand and 0.7 less than on the peat.

With regard to tiller production as judged by the numbers in early autumn the conclusion reached is that additions of lime on sandy soil do not effect any substantial increase. Indeed very large amounts may result in a decrease. On the other hand, on acid peaty soil tillering does not take place until lime be applied. Even at the lime requirement rate it is not abundant and may be less than on untreated sandy soil but with very heavy applications it becomes profuse in certain strains and may exceed the greatest found on sandy soil. On the whole, tillers are produced as freely on neutral clay loam as when conditions are at their best on either sandy or peaty soil.

Average leaf lengths taken in conjuction with the tiller counts were used again in the calculation of Indexes of Growth to shew the relative amounts of vegetation in early autumn. In the table of indexes below, no figures are given for the controls on the peaty soil since there was no tillering on these.

TABLE XXVI. DACTYLIS GLOMERATA. INDEXES of GROWTH.

Soil	Treatment	Danish	New Zealand	Welsh
Sandy	Control	.58	.64	.58
"	1 L.R.	.61	.63	.68
"	4 L.R.	.42	.76	.68
Peaty	Control	-	-	-
"	1 L.R.	.48	.37	.21
"	4 L.R.	.53	1.03	1.26
Clay loam	Nil	.23	.75	.68

A consideration of the Indexes of Growth show that when total growth is the basis of comparison the positions are in many cases altered from that decided on numbers of tillers. Thus on the sandy soil the heaviest liming gave in the case of the Danish strain the lowest growth index as it gave the smallest number of tillers; but in the case of the Welsh, the index at the heaviest rate was equal to that where the one lime requirement was supplied, showing that the extra length of leaf had counterbalanced the lower number of tillers. Also, the New Zealand strain on the same soil untreated, while it had 2.4 fewer tillers, had a slightly greater index of growth than when the lime requirement was given.

In the cases of the New Zealand and Welsh on the peaty soil receiving the one and four lime requirement treatments, the indexes show even greater increases than were suggested by the numbers of tillers. The New Zealand strain had on the latter treatment 2.06 times the number of tillers that it had on the former, whereas it had 2.78 times the amount of growth, and the Welsh strain with 3.5 times the number of tillers had 6.0 times the amount of growth.

Viewing in the early autumn the responses of growth as a whole to the treatments, it is seen that on sandy soil the addition of the lime requirement has had no appreciable effect on either the Danish or New Zealand strains but has increased the Welsh - the increase being due entirely to greater tillering. Greater tillering also occurred on the two former strains but was nullified by the shorter leaves. Four times the lime requirement depressed the Danish, increased the New Zealand and left the Welsh unchanged. The Danish owed its position to a decrease in tillers, the New Zealand to an increase of both tillers and leaf length, the Welsh to a decrease in tillers and increase in leaf length. All over, the New Zealand strain gave the greatest growth on this soil, the averages of the Indexes of Growth being, New Zealand .68, Welsh .65, Danish .54.

On the peaty soil without treatment, tillering did not take place but as judged by the average height of plants, equal growth was made by the Danish and New Zealand strains, the plants being taller and more vigorous than those of the Welsh strain. Where the lime requirement was given, a marked increase in growth was made by each strain. The order was Danish, New Zealand and Welsh. On the lime being increased to four times the requirement a further increase in growth was shown by all but the order was reversed - Welsh, New Zealand and Danish. The Indexes of Growth suggest that on this soil, while the Danish strain benefits much from lime at the requirement rate there is little further gain by increasing this four times; whereas the New Zealand and Welsh strains do not give so much growth at the lower rate but increase greatly at the higher rate giving double the growth of the Danish strain. Making allowance for the height of the plants on the untreated soil, for which no Indexes of Growth are given, the average amounts of growth over all on this soil do not differ much, that of the New Zealand and Welsh being equal and slightly greater than that of the Danish.

The Danish strain on the clay loam gave very poor growth - the poorest of all for this strain with the exception of that on the untreated peaty soil. The New Zealand and Welsh strains on the other hand were almost as good on the clay loam as on the sandy soil treated at the four lime requirement rate, not nearly so good as on the peaty soil receiving the four lime requirement but much better than where the one lime requirement was given to the soil. Against this has to be offset the comparative fewness of the plants produced on the clay loam, and the fact that the above comparisons were made from plant averages after the young seedlings had been thinned to leave the same number of plants per pot. On this soil receiving large increments of lime - up to 80% of the weight of soil, the behaviour of the Welsh strain was irregular, both as regards number of seedlings produced and subsequent growth.

PHLEUM PRATENSE

The strain used in the first series of experiments was similar to that referred to as "Scotch" in the second and the soil on which it was grown tended in character to that of the peaty soil of Series II though the organic matter content was not quite so high. Confirmation was obtained of the earlier results, namely that this grass benefits greatly from lime added at the lime requirement rate to an acid soil containing much organic material and that further benefit accrues from still heavier rates. The advantage is not confined to any one period but is continuous from the first appearance of the seedlings.

Comparing the numbers of seedlings present a month after sowing the seeds it was found that on the average for all soils and treatments, the Scotch and Gloria strains were equal, with the Welsh much behind. The average numbers per 100 seeds were - Scotch 71.1, Gloria 71.8, Welsh 52.2.

As judged by numbers, all three strains shewed a very poor response on acid sandy soil to the addition of lime either at the requirement rate or at four times that rate. On peaty soil the response was much greater and was continued with the higher rate of treatment.

Since the germinations of the Scotch and Welsh strains were five and four per cent, respectively greater than that of the Gloria, the numbers of seedlings have been calculated as percentages of the germination figures, so that a truer comparison may be obtained. As before, the official germination figure has been assumed as representing the maximum possible number of plants which might be produced. Table XXVII shows the relative positions on this basis.

TABLE XXVII. PHLEUM PRATENSE

Percentages of Possible Number of Plants at 39 Days after Sowing Seed.

Soil	Treatment	Scotch	Welsh	Gloria
Sandy	Control	94.1	47.6	87.5
"	1 L.R.	96.4	50.0	90.0
"	4 L.R.	98.8	57.1	90.0
Peaty	Control	44.7	61.9	62.5
"	1 L.R.	82.3	69.0	97.5
"	4 L.R.	95.3	83.3	100.0
Clay loam	Nil	80.0	59.5	95.0
Average		84.5	61.2	88.9
Official Germination		85%	84%	80%

The percentages of the possible numbers produced by the Scotch and Gloria strains are seen to be remarkably high. Indeed Gloria on peaty soil receiving four lime requirements developed a plant for every seed indicated by the test as viable. Gloria, a Swedish strain, gave the highest average, closely followed by the Scotch strain. The Welsh strain, though having almost as high a germination figure as the Scotch gave over 20% fewer plants. It may be remarked that this strain is very different in character from the others. It is an indigenous selection made by the Welsh Plant Breeding Station and intended definitely for grazing. The seeds are slightly smaller and the plants are smaller in every way than the Scotch or Gloria. The leaves are fine and numerous and in certain circumstances the plants tiller profusely.

For all treatments on the sandy soil, the Scotch strain gave a higher percentage of the possible than the Gloria and both of these much higher than the Welsh, but the differences between the percentages on the untreated soil and that receiving its lime requirement were practically the same for the three strains, - actually, Scotch 2.3, Welsh 2.4, Gloria 2.5. With the increase of lime to four times the requirement the Scotch made the further increase of 2.4, the Welsh 7.1 and the Gloria 0.0.

On the peaty soil as a whole the Gloria strain gave the highest percentage of plants, and the Welsh was not far below that of the Scotch. The percentage increases made at the lime requirement rate over the untreated soil were - Scotch 37.6, Welsh 7.1, Gloria 35.0. The further increases with the four lime requirement rate were - Scotch 13.0, Welsh 14.3, Gloria 2.5. It therefore appears that when acid peaty soil receives its lime requirement many more plants of the Scotch and Gloria strains and a few more of the Welsh strains will be produced. Almost the maximum possible number of Gloria plants having appeared at the lime requirement rate only a few more could be obtained when four times the requirement was given. The increase however was continued by the Scotch and Welsh strains, that of the latter being double its first increase.

As far as number of seedlings is concerned the effect of lime on the Scotch strain was small on sandy soil but was continued to four times the requirement on peaty soil; on the Welsh it was continued on both soils; on the Gloria it was small on the sandy soil and virtually ceased at the lime requirement rate on the peaty soil.

The percentages of plants on the neutral clay loam varied considerably for the different strains but occurred in the same order as the overall averages and in the same order as the percentages on the peaty soil receiving the lime requirement.

The growth of all strains proceeded steadily on the sandy and clay loam soils. Gloria grew most rapidly and the Welsh strain most slowly but for all strains there was an obvious increase in height of the plants with the addition of lime at the requirement rate and a further increase at four times that rate. On the peaty soil growth was in all cases very hesitant at first but ultimately where lime was given the plants proceeded healthily, again being taller at the higher rate. Where no lime was given growth was much retarded and many plants failed to survive the seedling stage. Between spring and autumn the numbers of the Scotch strain fell from 44.7% of the possible to 28.2%. of the Welsh from 61.9% to 13.1%; of the Gloria not a single plant remained.

Phleum pratense was the only species of grass dealt with that flowered in the seedling year, and the actual time at which this occurred was influenced by the rate of liming. Seven weeks from sowing the seed of the Scotch strain, spikes began to emerge from the plants on sandy soil treated at the four lime requirement rate.

Four days later they appeared on the same soil receiving the one lime requirement and sixteen days later on the untreated soil. Also on this soil at the heavier rate the Welsh strain produced its first inflorescence a week later than the Scotch. Again where the one requirement was given the spikes were four days later. The Gloria strain at the four and one lime requirements developed spikes at the same times as the Scotch strain. The Scotch strain was the only one to produce inflorescences on sandy soil receiving no lime and on the clay loam. Only one flower head was seen on the peaty soil - treated or untreated and that was from the Scotch strain where the lime requirement was given.

Tiller counts made in early autumn revealed that on sandy soil treated at the lime requirement rate the Scotch strain developed a greater number of shoots than where no lime had been given but the number was not further increased at four times that rate - indeed it was depressed to nearly that on the untreated soil. The Welsh strain increased its numbers at both rates, having fully twice as many at the higher rate as where no treatment was given. The Gloria strain was little influenced.

On the peaty soil Gloria produced no tillers at all, the Scotch and Welsh strains produced none in the absence of lime, a few where lime was given but no substantial increase at the higher rate.

Tillering by the Welsh strain on the clay loam was profuse - an average of 18 tillers per plant. The Scotch gave just over half this number and Gloria only a sixth.

It may be concluded then that in addition to the greater natural tendency of the Welsh strain to produce tillers it is also more susceptible to the influence of lime than the others and can respond to larger quantities.

Combining the figures for average tiller numbers with these for average leaf length in early autumn to give Indexes of Growth as before the results given in Table XXVIII are obtained.

TABLE XXVIII. PHLEUM PRATENSE. INDEXES of GROWTH.

Soil	Treatment	Scotch	Welsh	Gloria
Sandy	Control	.84	.48	.39
"	1 L.R.	1.68	1.12	.41
"	4 L.R.	.83	1.46	.48
Peaty	Control	-	-	-
"	1 L.R.	.48	.18	-
"	4 L.R.	.91	.31	-
Clay loam	Nil	1.27	1.35	.15

The above figures show that by early autumn the Scotch had given much the greatest growth of the three strains on sandy soil untreated and treated at the lime requirement rate; also that the increase obtained by the treatment was greatest for the Scotch strain. The increases as shown by the differences in the Indexes of Growth were - Scotch .84, Welsh .64, Gloria .02. At four times the lime requirement rate the Scotch fell back but the Welsh and Gloria made further slight gains.

On the peaty soil no tillering occurred in the absence of lime though the plants of the Scotch strain were slightly taller than these of the Welsh. As previously mentioned no Gloria plants survived here. At the one lime requirement tillers were produced and leaf lengths increased by both Scotch and Welsh strains with an increase in both at four times the lime requirement. At both treatments the Scotch gave much the greatest growth. Gloria formed no tillers on this soil at all nor was the leaf length increased by the heavier rate of liming. This strain gave very feeble growth on the clay loam whereas the Scotch and Welsh tillered strongly and had good leaf length. Indeed, as the Indexes of Growth show, their performances here were only equalled by that of the Scotch on the sandy soil receiving its lime requirement and by the Welsh on the same soil receiving four times the lime requirement.

Besides showing that in all cases increased growth can be obtained from these grasses by adding the lime requirements to acid soils, these results are of interest in showing the different behaviour on different soils. It is generally accepted that Phleum is eminently suited to soils with a large clay fraction. The responses here are in accordance with that belief except in the case of the Gloria strain which in these experiments did not fulfil its early promise. Further, this species is often held to be one of the most successful on peaty soil. It has not been found so here. On the contrary all strains considered have given superior growth on sandy soil.

ALOPECURUS PRATENSIS.

The germinating capacity of the seed of this species is generally low. The seed used for the experiments had only a germination of 73% but in addition to that it was found that only a comparatively small number of the seeds, indicated as viable by the germination test, actually produced plants. The numbers of plants which might possibly have grown, assuming that every so called viable seed under some circumstances could have developed a plant have been calculated as percentages and are given in Table XXIX.

TABLE XXIX. ALOPECURUS PRATENSIS.

Percentages of Possible Number of Plants
at 37 Days after Sowing Seed.

Soil	Treatment	Percentages
Sandy	Control	60.3
"	1 L.R.	60.3
"	4 L.R.	63.0
Peaty	Control	10.9
"	1 L.R.	24.7
"	4 L.R.	32.9
Clay loam	Nil	49.3

While the percentages are low, they are, on the sandy soil, very consistent and show no evidence of having been influenced by the additions of lime. On the untreated peaty soil the plants were fewest of all and were slow to appear. Although the numbers were still small for either lime treatment they showed considerable increases.

Subsequent behaviour proved the addition of lime to be beneficial on both sandy and peaty soils. On the former it gave not only increased length of leaves but a greater number of tillers; on the latter it prevented the complete dying off of the plants as occurred where no treatment was given but it was unable to prevent a reduction in numbers or to produce any robust tillering plants.

The relative positions in early autumn are given by the Indexes of Growth in Table XXX calculated in the usual way.

TABLE XXX. ALOPECURUS PRATENSIS. INDEXES of GROWTH.

Soil	Treatment	Indexes
Sandy	Control	.38
"	1 L.R.	1.17
"	4 L.R.	1.59
Peaty	Control	-
"	1 L.R.	-
"	4 L.R.	-
Clay loam	Nil	.78

POA TRIVIALIS

In the case of this grass the results from the earlier trials were very like those from the experiments carried out later on sandy soil. The addition of lime gave decidedly increased growth even when continued considerably beyond the lime requirement rate, and at the higher rates the plants became more bushy and compact.

Seedling counts showed that a high percentage of the seeds produced plants on sandy soil, on clay loam the percentage was rather less and was poorest on peaty soil.

Table XXXI below, shows the numbers calculated as percentages of the possible number of plants or of the seeds indicated as viable by the germination test.

TABLE XXXI. POA TRIVIALIS.

Percentages of Possible Number of Plants at 37 Days after Sowing Seed.

Soil	Treatment	Percentages
Sandy	Control	76.9
"	1 L.R.	78.0
"	4 L.R.	80.2
Peaty	Control	4.4
"	1 L.R.	61.5
"	4 L.R.	59.3
Clay loam	Nil	72.5

The increase of 1.1% and the further increase of 2.2% on the sandy soil do not justify a claim for lime having influenced the number of seedlings either at the requirement rate or four times that rate. On the other hand it proved very effective at the requirement rate on the peaty soil, raising the numbers from 4.4% to

61.5%, but no further increase resulted from the four lime requirement rate.

Though the numbers were not much affected by the lime on sandy soil the subsequent growth was decidedly influenced. Where the soil was left untreated the leaf length was quite as great as at the lime requirement rate but fewer tillers were developed: and at the four lime requirement rate both leaf length and number of tillers were increased.

No plants survived on the untreated peaty soil, and though numbers were reduced, tillering occurred on the addition of lime with further slight increase both of tillers and leaf length at the four lime requirement rate.

The relative amounts of growth showing in early autumn are indicated below in Table XXXII.

TABLE XXXII. POA TRIVIALIS. INDEXES of GROWTH.

Soil	Treatment	Indexes
Sandy	Control	.78
"	1 L.R.	.90
"	4 L.R.	1.56
Peaty	Control	-
"	1 L.R.	.09
"	4 L.R.	.12
Clay loam	Nil	.49

Cynosurus cristatus, Agrostis vulgaris and Festuca ovina were not dealt with in detail but in the observational trials it was seen that both Cynosurus and Agrostis tended to grow more quickly in the early stages where the heaviest application (three times the lime requirement) of lime had been given. No outstanding benefit was maintained from the liming except that Cynosurus commenced growth rather earlier in spring. The only case encountered where liming appeared to retard seedling growth was that of Festuca ovina, and that only at rates higher than the lime requirement. In spite of this a high rate enabled the plants to survive the winter more successfully and like Cynosurus start into growth earlier in spring.

PLOT EXPERIMENT

GRASS SPECIES on SOIL of LOW LIME REQUIREMENT with ADDED INCREMENTS of LIME.

The objects of this experiment were to find,

(1) Whether several of the more common grass species when grown on soil which did not exhibit a marked acidity or lime requirement would make any visible response to additions of lime; and

(2) Whether the calcium and nitrogen content of any of the species was altered by such additions of lime.

PROCEDURE.

The soil - a medium loam - at the gardens of Auchincruive, Ayr, was found to be suitable and by the courtesy of the Horticultural Dept. of the West of Scotland Agricultural College the experiments were conducted there.

On testing, the soil showed the following -

pH 6.78
Lime requirement (Hardy) 0.082% $CaCO_3$.

Thirty two plots, each 4 ft. by 4 ft. were laid off so that the total block (exclusive of 1 ft. paths) measured 32 ft. by 12 ft. - eight rows with four plots in each. The plots in each row received respectively calcium carbonate at the following rates.

(1) Control - No lime
(2) Lime requirement (1 L.R.)
(3) Twice the Lime Requirement (2 L.R.)
(4) Thrice the Lime Requirement (3 L.R.)

Each row of plots was devoted to a single species, thus -

(i) Lolium perenne, L.
(ii) Dactylis glomerata, L.
(iii) Phleum pratense, L.
(iv) Festuca pratensis
(v) Cynosurus cristatus, L.
(vi) Poa trivialis, L.
(vii) Festuca ovina, L.
(viii) Agrostis vulgaris, With.

From Armstrong's figures (3) for the average weights per thousand seeds of the various species, the weights required per plot to give a seeding of four seeds per square inch, were calculated. These small amounts were diluted with fine dry sand and sown during the last week of April - a month after the lime had been incorporated with the soil.

It was intended to leave the plots undisturbed for two years and make periodical observations of any differential responses in growth and development to the soil treatments. Soon, however, it became obvious that difficulty from weeds was to be encountered.

In view of the sparse early growth of the grasses and the more vigorous growth of weeds on some plots than others the alternatives were the complete clearing of all the plots with subsequent repeated weedings before resowing the grasses, or leaving them untouched for a time, in the hope that the grasses would be able to establish themselves sufficiently in spite of the strong competition to allow of weeding later. The latter alternative was chosen as entailing the less labour and as having the possibility of supplying some information as to how the soil treatments influenced the weed growth.

Seven weeks after sowing the grass seeds there was a strong weed growth on all plots, becoming increasingly profuse with the increase in lime. The most prevalent weeds were Sonchus oleraceus (L), Stellaria media (Vill.) Polygonum Persicaria (L) and Lamium purpureum (L). So overpowering were the weeds by this time that the Cynosurus cristatus, Poa trivialis, Festuca ovina and Agrostis plots were hoed up and reseeded. The others had made a sufficient stand to permit of weeding.

Up till the autumn of the first year there was little difference in the growth of the grasses which could be attributed to the different rates of liming. However Dactylis, Phleum and Festuca pratensis apparently found conditions rather more favourable to them in the combat with weeds on the 1 L.R. plots than on the others. The same was the case with Cynosurus, Poa and Agrostis. In fact it was only on the 1 L.R. plots that these three were able to gain any hold at all at the first sowing.

The interest, therefore in the early stages centres mainly round the weeds. On the Lolium perenne plots, Sonchus was the only weed on the control, while on the limed plots there were equal amounts of Sonchus and Stellaria. None of the Dactylis, Phleum or Festuca pratensis plots was occupied by only one weed species but the growth of Stellaria, Sonchus and Persicaria became increasingly dense from the control to 3 L.R. The control and 1 L.R. of the Festuca ovina plots prior to re-seeding were covered mainly by Sonchus while Stellaria occupied the heavier limed plots. On the controls, 1 L.R. and 2 L.R. of the Cynosurus and Poa plots, Sonchus predominated while 3 L.R. was held by Stellaria. The Agrostis control showed Sonchus only, 1 L.R. carried Sonchus and Persicaria, while on 2 L.R. and 3 L.R. there was a very dense growth of Sonchus, Persicaria, Stellaria and Lamium.

From these observations it would seem that all the weeds mentioned with the exception of Sonchus were more vigorous the greater the amount of lime, the most consistent in this respect being Stellaria. But Sonchus flourished most on the untreated soil.

OBSERVATIONS on GRASSES.

Lolium perenne. Throughout the first and second winters the plants remained very green showing little winter burn. In the spring 1 L.R. showed a slightly greater growth than the other plots which were equal. During summer and autumn no differences in growth could be detected.

Dactylis glomerata. During the first summer a uniformly strong growth was made on all plots. This began to burn early in autumn and by mid-winter the plots were covered with a mass of decaying leaves. This species was decidedly the most prone of all to winter-burn. In spring there was a slightly increasing growth with increased lime. The only difference noticeable during summer was the lesser tendency of the plants on the control to lodge.

Phleum pratense. Winter burnwas seen to some extent on the control and 1 L.R. plots. Much less was present on 2 L.R. while 3 L.R. was almost free, the plants being much greener than on the other plots. In spring the growth on the control and 1 L.R. plots was equal, on 2

L.R. and 3 L.R. it was equal though the plants there were taller than on the two former plots. With the advancing season differences in height disappeared but on 2 L.R. and 3 L.R. the stems were softer and the plants more leafy than on the control and 1.L.R.

Festuca pratensis. The plots gave a uniformly vigorous growth during summer and all burned very readily in winter. In early spring the plants on 2 L.R. and 3 L.R. were slightly taller than on the other plots, otherwise no difference was seen at any time.

Cynosurus cristatus. All plots showed the same considerable amount of winter burn which lasted on into March. Spring growth was uniform though the plants became more tufted with increase of lime. Holcus lanatus made its appearance in increasing amount with increase of lime. By summer (June) the growth was greatest on 2 L.R. followed by 1 L.R. The control and 3 L.R. were equally poor in comparison.

Poa trivialis. The first summer all plots produced a strong close growth which remained green and unburned throughout the winter. By the following March when new growth had commenced, the plants on 2 L.R. and 3 L.R. were equal and slightly taller than those on 1 L.R. which

Photograph 18.

Festuca ovina Plots. May of second year. Back to front; Control, 1.L.R., 2 L.R., 3 L.R.

Photograph 19.

Agrostis vulgaris Plots. May of second year. Back to front; Control, 1 L.R., 2 L.R., 3 L.R.

in turn were taller than those on the control. During the next month the difference between the control and the other plots became more pronounced, the greatest growth being seen on 3 L.R. As maturity was reached the differences in the heights of the plants on the treated plots disappeared though that between the control and the treated plots remained. On the control too, the "sole" was opener than on the others.

Festuca ovina. (Photograph 18). At no time was there any noticeable difference in growth of individual plants due to the treatments. There was however a slight decrease in the amount of winter burn with increase in lime up to 3 L.R. Also the number of plants reaching maturity on 3 L.R. was less than on the other plots, which was at least partly due to the recurrent weed growth where liming was heaviest.

Agrostis vulgaris. (Photograph 19) During the first summer and winter no differences were seen. By the second spring the control showed an even cover and was greenest, whereas the treated plots were patchy though the individual plants were taller than on the control. This was largely due, as in the case of Festuca ovina to the repeated establishment and removal of weeds.

CHEMICAL ANALYSES.

In the second week of June of the second year, the plots were cut and sampled for chemical analysis. The stage at which each grass was, at the time of sampling, is indicated below.

Lolium perenne	- Flowering, anthers protruded.
Dactylis glom.	- Flowering past one week.
Phleum prat.	- Inflorescence emerging from sheath.
Festuca prat.	- Inflorescence almost fully developed.
Cynosurus crist.	- Inflorescence fully developed.
Festuca ovina	- Inflorescence fully developed.
Agrostis vulgaris	- Inflorescence emerging from sheath.

Determinations of the amounts of calcium and nitrogen were made to find whether these had been influenced by the treatments. The averages of duplicate analyses as percentages of the air-dry weights are given in Table XXXIII.

TABLE/

TABLE XXXIII. PERCENTAGES of NITROGEN and CALCIUM (as CaO) in AIR-DRY WEIGHTS of GRASSES.

Species	Treatment	CaO %age	Nitrogen %age.
Lolium per.	Control	0.518	1.994
"	1 L.R.	0.472	1.704
"	2 L.R.	0.574	1.838
"	3 L.R.	0.528	1.637
Dactylis glom.	Control	0.395	1.603
"	1 L.R.	0.406	1.562
"	2 L.R.	0.364	1.508
"	3 L.R.	0.371	1.455
Phleum prat.	Control	0.479	1.724
"	1 L.R.	0.423	1.623
"	2 L.R.	0.514	1.939
"	3 L.R.	0.514	1.926
Festuca prat.	Control	0.771	1.690
"	1 L.R.	0.651	1.548
"	2 L.R.	0.759	1.818
"	3 L.R.	0.743	1.725
Cynosurus crist.	Control	0.402	1.333
"	1 L.R.	0.378	1.361
"	2 L.R.	0.448	1.320
"	3 L.R.	0.528	1.361
Festuca ovina	Control	0.260	1.306
"	1 L.R.	0.257	1.267
"	2 L.R.	0.257	1.320
"	3 L.R.	0.360	1.670
Agrostis vulg.	Control	0.540	1.918
"	1 L.R.	0.504	2.079
"	2 L.R.	0.523	2.331
"	3 L.R.	0.584	2.205

DISCUSSION

On the whole, only small responses were made to additions of lime to a medium loam, which according to the Hardy test showed a very low lime requirement.

For a short time in the second spring Lolium perenne grew rather taller at the lime requirement than at the other rates of treatment. The calcium content of the plants from this treatment proved later to be the lowest of any, while the nitrogen content was 0.29% less than where no treatment had been given.

Dactylis was not visibly affected by additions of lime. Its calcium content varied slightly but irregularly while its nitrogen content fell gradually with increased application of lime.

The case of Phelum pratense is interesting. Both as regards visible and chemical responses the plots fell into pairs, the control and one lime requirement plots together and the two and three lime requirement plots together. The latter showed less winter burn, more vigorous growth, greater succulence and leaf development and higher percentages of calcium and nitrogen than the two former.

The only effect which Festuca pratensis displayed was in the slightly greater height in spring of the plants on the two plots receiving the higher rates of liming. This was reflected in the higher nitrogen contents of these plants.

The growth responses and the contents of calcium and nitrogen of Cynosurus were irregular.

Chemical analyses were not made for Poa trivialis but observations showed that rates up to three times the lime requirement gave increased early growth. The effect of lime too, was noticeable on this grass in giving a closer and more uniform sward, as the result of greater tillering.

Although additions of lime had little influence on the growth of Festuca ovina it did as in the case of Phleum tend to reduce the amount of winter burn to which this grass is rather prone. The highest rate of liming had the further effect of raising the percentages of lime (CaO) and nitrogen by 0.10 and 0.36 respectively. It seems possible that the amount of winter burn is related to the calcium and nitrogen content. In these trials, Agrostis remained very winter-green and its content of calcium and nitrogen were remarkably high.

Viewing the chemical analyses as a whole, it does not appear that additions of lime to a soil such as was used in this experiment, whose lime requirement was low, effects any consistent increase in the lime content of the usual pasture grasses. Indeed, in all but one case - Dactylis - the addition of the small lime requirement resulted in a fall in the calcium content. Higher rates did on occasions give an increase but not always.

PASTURE EXPERIMENT

The Effect of Calcium Carbonate on Herbage and on Soil Reaction.

In 1928 experiments were initiated to discover the effects over a number of years of applications of lime in the form of calcium carbonate to pasture land which showed definite acidity and need of lime. While the main object in view was to obtain data on the floristic change induced by the treatments it was also hoped that determinations of the altered reactions of the soil might be of value.

PROCEDURE and RESULTS

That results might be of wide application eight experimental centres were chosen at scattered points throughout the south west of Scotland. Soils were sampled, the pH and lime requirements ascertained lime applied accordingly and a number of preliminary observations made, but the difficulties of adequate supervision and a variety of other causes necessitated the abandonment of all but three centres. These were located on the farms of Tullichewan by Balloch, Ellisland by Dumfries, and Woodhall by Annan.

As a preliminary the pH (water) value and lime requirement of the soil at each centre was determined to ascertain whether the centre presented a suitable subject for experimentation. Thereafter at each centre four $\frac{1}{8}$ acre plots were laid off, - two controls (untreated) one receiving ground limestone sufficient to supply calcium carbonate at the lime requirement rate, and one receiving limestone at a rate equivalent to 2 tons calcium carbonate per acre. The arrangement is shown in the diagram below.

ARRANGEMENT of PLOTS

Plot (1) Control	Plot (2) 2 tons per acre
Plot (4) L.R.rate	Plot (3) Control

The reason for the inclusion of a standard 2 ton rate of treatment in the experiment was that it is the rate arrived at empirically by agriculturists as a "good average dressing" of lime for acid soil and it was desired to ascertain how the results from it compared with those from rates calculated from chemical determinations.

The lime requirements on which applications were based were found by the Hutchinson and McLennan method, as at the time when these experiments commenced this was the only method employed in advisory work. However, at a later date the lime requirement of the soil samples was found by the Hardy method also, purely for purposes of comparison. The preliminary data for the three centres are given in Table XXXIV below.

TABLE XXXIV. PRELIMINARY SOIL DATA.

Centre	pH	L.R.(H & McL) % $CaCO_3$	L.R.(Hardy) % $CaCO_3$
Tullichewan	4.70	0.283	0.315
Ellisland	5.17	0.383	0.495
Woodhall	4.77	0.600	0.626

TULLICHEWAN

At Tullichewan the soil was a medium to heavy loam containing 8.5% of organic matter and the field in which the plots were located was occupied by old permanent pasture dominated by Agrostis and Holcus. Galloway bullocks grazing the surrounding field had free access to the plots.

The first evidence that the lime was beginning to have an effect was seen six months after it had been applied. The limed plots, particularly that receiving the lime requirement rate (2 tons 16 cwt. calcium carbonate per acre) were being a little more closely grazed by the stock. This was evident though there was no noticeable difference in the botanical composition of the herbage of the various plots. This differential grazing was continued throughout the experiment and after two years the limed plots were quite distinct from those unlimed. They showed a more vivid green and the amount of Agrostis was diminishing rapidly. Still the lime requirement plot had the advantage. At this time a remarkable number of thistles (Cnicus arvensis, Hoff) appeared on the limed plots. These occupied 15% of the plot receiving the standard application and 10% of that receiving the lime requirement rate. Only occasional plants occurred on the control plots while the rest of the field was almost entirely free from them.

After four years the boundaries of the limed plots were clearly demarked by the brighter green colour, the greater depasturing and the change in the proportions of the component species. To measure the changes which had been induced, careful botanical analyses were made by the "Point Quadrat"* method. The analyses of the two

* See Appendix A.

control plots have been averaged and placed beside those of the limed plots in Table XXXV.

TABLE XXXV. TULLICHEWAN.

Percentage Botanical Analyses* to show Changes induced by Two Rates of Liming after Four Years.

Species	Plots		
	Control	Standard Rate (2 tons $CaCO_3$)	L.R.Rate (2 tons 16 cwt. $CaCO_3$)
Agrostis spp...........	51	21	6
Holcus lanatus, L......	19	15	17
Anthoxanthum odor., L...	10	4	4
Festuca ovina, L.......	5	19	27
Poa spp................	4	10	15
Cynosurus cristatus, L.	-	2	3
Dactylis glomerata, L..	1	2	4
Trifolium repens, L....	5	17	12
Ranunculus acris, L....	5	7	7
Bellis perennis, L.....	-	3	3
Prunella vulgaris, L...	-	-	2

That note might be made of the changes in soil reaction resulting from the treatments, samples were drawn at two and four years from the commencement of the experiment and tested for hydrogen ion concentration and lime requirement. The results obtained are given below in Table XXXVI.

* The analyses are those of the herbage without thistles. The contribution made by these could not be measured because the farmer, aggravated by their conspicuousness had mown them down two days prior to the date of analysis.

TABLE XXXVI. TULLICHEWAN. LIMED PLOTS

SOIL DATA TWO AND FOUR YEARS after TREATMENT

After	Treatment	pH	L.R.(H.& McL)	L.R.(Hardy)
2 years	Standard rate	5.78	0.112	0.150
4 "	"	5.99	0.126	0.231
2 "	L.R.rate	6.02	0.096	0.191
4 "	"	5.73	0.088	0.292

ELLISLAND

The soil of the field at Ellisland on which the plots were laid off was very fine, sandy and open textured containing only 4.5% of organic matter and a great many stones. The soil itself and the vegetation growing thereon indicated a very low state of fertility. This field had been lying under so-called permanent pasture for an unknown number of years, the herbage consisting almost exclusively of Agrostis, Holcus and Anthoxanthum. The grazing animals in this case were Blackface sheep.

As at the previous centre the effect of the treatments began to be seen after about six months, in the greener and healthier appearance of the grasses. The plot receiving the standard application looked slightly more promising than that treated at the lime

Photograph 20.

Ellisland. Foreground, "Standard" plot; beyond, Control.

Photograph 21.

Ellisland. Right, ungrazed Holcus of Control; Left grazed herbage of "Standard" Plot.

requirement rate (3 tons 16 cwt. per acre).

At two years from the time of treatment a noticeable difference was taking place. The sheep were tending to graze down the limed plots, particularly that treated at the standard rate, more than the surrounding areas which were rough and tufted with much withered material (Photographs 20 and 21). Agrostis and Anthoxanthum were decreasing in amount and were being replaced mainly by Cynosurus cristatus.

During the following two years the changes went on continuously. More and more were the limed plots cropped down closely and Cynosurus from being present in very small amounts became the dominant species.

Only on the limed plots did thistles (Cnicus lanceolatus, Hoff.) appear.

The botanical analyses at the conclusion of the experiment are given in Table XXXVII.

TABLE/

TABLE XXXVII. ELLISLAND

Percentage Botanical Analyses showing Changes induced by Two Rates of Liming after Four Years.

Species	Plots		
	Control	Standard Rate (2 tons $CaCO_3$)	L.R.Rate (3 tons 16 cwt. $CaCO_3$)
Agrostis spp........	43	8	9
Holcus lanatus, L...	28	16	25
Anthoxanthum odor., L.	25	2	8
Cynosurus cristatus, L................	3	56	41
Trifolium repens, L.	trace	10	6
Bellis perennis, L..	-	trace	-
Leontodon hispidus, L.......	-	2	-
Musci spp...........	-	3	8
Ranunculus acris, L.	-	-	2
Plantago lanceolata, L................	-	trace	trace
Prunella vulgaris, L.	-	trace	-

The reactions of the soils to the different treatments at two and four years after the application of the lime are given in Table XXXVIII below.

TABLE XXXVIII. ELLISLAND. LIMED PLOTS.

Soil Data Two and Four Years after Treatment.

After	Treatment	pH	L.R.(H.& McL)	L.R.(Hardy)
2 years	Standard rate	5.45	0.244	0.461
4 "	"	5.81	0.108	0.371
2 "	L.R. rate	5.71	0.211	0.360
4 "	"	6.16	0.271	0.218

WOODHALL

At this centre the soil was a light loam with a fairly high organic matter content - 13.8%. The field where the experiment was conducted did not carry old pasture as in the previous cases but was sown down to grass the same year as the applications of lime were given. The oat "nurse crop" with which the grass seeds were sown yielded considerably more grain from the treated plots than from the controls, the heaviest yield being from that receiving the lime requirement rate (6 tons per acre). Oats are usually considered to be little affected by acid conditions but apparently the degree of acidity encountered here was such as to depress the productivity markedly.

Accurate botanical analyses of the plots were not made but it became early apparent that the success of the grasses depended on the amount of lime applied. On the plot treated at the lime requirement rate the number of grasses establishing themselves and the growth of these was greatest. While on the plot treated at the standard rate growth and establishment were better than on the controls they were not quite so good as where the full lime requirement had been given. In the absence of lime, establishment and subsequent growth of sown species were poor but weed growth was profuse. Spergula arvensis, L. was most prevalent in the early stages.

Lolium perenne, was frequent on all plots but was much more vigorous in the presence of lime.

Dactylis glomerata was more plentiful on the treated plots than on the controls where only a few plants were in evidence.

Phleum pratense was scarce on both the controls and the plot treated at the standard rate, but was more in evidence where the lime requirement was given.

Cynosurus cristatus appeared in small quantity on both the limed plots but was absent from the controls.

Agrostis, entirely absent from the lime requirement plot, was very scarce on the standard plot while small amounts were seen on the controls.

Holcus lanatus, while fairly common on both the limed plots was much more abundant on the controls.

Poa annua and Rumex acetosella were plentiful but decreased in amount with increased lime. On the other hand Bellis perennis and Leontodon hispidus became more prevalent with increasing lime.

DISCUSSION of RESULTS.

At each centre where calcium carbonate was applied to acid soil at a standard rate of 2 tons per acre and at a rate indicated by the Hutchinson and McLennan lime requirement test (which was always greater than the standard rate), the amounts of Agrostis were reduced. The reductions were always considerable though at one centre it was almost the same for both treatments while at the others it was greatest at the lime requirement rate. Although the Rothamsted plots, referred to earlier, were cut for hay while here the plots were grazed, and though the initial acidity was not so great, the same tendency was seen to a reduction in the amount of Agrostis subsequent on liming.

It is generally accepted that Holcus is much reduced by liming. In these experiments only a slight reduction was recorded after four years. Casual comparison of treated and untreated plots might have led one to suppose that at least half of the Holcus had been eliminated but actual counts revealed that in most cases there were almost as many plants present as before, though these were much lower as a result of the more intense grazing, and their leaves were more intermingled with those of adjacent species.

On the two centres where Anthoxanthum odoratum was prevalent, marked diminution was effected by the treatments. At one centre there was an equal reduction from both treatments. Less than half the original number of plants remained. At the other, a third remained on the lime requirement plot and only a twelfth on the standard rate plot. These results are in accordance with the Rothamsted findings where rather less than half the Anthoxanthum plants survived. There is also agreement in that, next to Agrostis this grass is susceptible of the greatest reduction by lime. At Rothamsted only between a fifth and a sixth of the Agrostis plants remained after treatment while in the present experiment it was found that the averages for the two rates of treatment at two centres were approximately a fourth and a fifth.

Festuca ovina and Poa at one centre gave remarkably responsive increases to the treatments. At the standard rate Festuca was approximately four times and at the lime requirement rate more than five times as numerous as on the control area. The corresponding figures for Poa were two and a half times, and three and three quarter times. This is probably quite normal behaviour for Poa. Indeed the Rothamsted figures show an increase of rather more than ten fold but the contribution of the species to the total herbage was small (0.15% and 1.94%) in comparison to that in the case under consideration.Festuca ovina on the contrary, is usually found in greatest amount where acid conditions prevail and at Rothamsted it was depressed by lime. It should however be noted that in this instance, next to Agrostis, Holcus and Anthoxanthum, Festuca was the most prevalent grass present in the untreated pasture. Further, its habit of growth is such that severe defoliation does not tend to kill it. If then, as has previously been shown, the addition of lime per se is at least not inimical to this species the increases can be clearly attributed in large measure to the removal of the aggression of Agrostis, and Anthoxanthum.

Cynosurus cristatus increased in the presence of lime at each of the three centres. At two it could not be detected at all on the untreated areas. It made a definite appearance where lime had been given but only in small amount. At one centre, though its contribution to the whole on the controls was small, it was clearly present and struggling for existence against large amounts of Agrostis, Anthoxanthum and Holcus. When the two former were reduced as a result of the liming (and the grazing) it increased enormously. Whereas it contributed only 3% to the whole on the controls it gave 56% at the standard rate and 41% at the lime requirement rate. These amounts were in inverse proportion to those contributed by the Agrostis, Anthoxanthum and Holcus, thus:-

	Standard rate	L.R. rate
Agrostis + Anthoxanthum + Holcus	26%	42%
Cynosurus cristatus.............	56%	41%
Sum	82%	83%

Dactylis glomerata was entirely absent from one centre and at the others it was present only in very small amount. It did however show a slight tendency to increase with increased applications of lime.

Consistently at one centre (Ellisland) the response of the pasture as a whole and of each of the component species was more marked on the plot receiving the standard (2 tons calcium carbonate per acre) application of lime than on that treated at the lime requirement rate (3 tons 16 cwt. calcium carbonate per acre). The results from the other two centres detailed and from centres at which the experiments were not completed, indicated that such behaviour was unusual. Generally, treatment at the lime requirement rate induced greater responses from the vegetation than treatment at the standard 2 ton rate.

At Ellisland both the type of vegetation and the sandy, weathered, structureless appearance of the soil suggested that a deficiency of plant nutrients as well as the acid reaction contributed to the infertility. If this were so, it is possible that the smaller amount of calcium carbonate being sufficient to lower the acidity somewhat, and to supply the necessary calcium for nutritional purposes, gave a better balance of nutrients in the soil.

The changes in soil reactions and reponses to the lime requirement tests resulting from the different treatments are of interest.

Commencing with a pH value of 4.70, the standard rate raised the value to 5.78 after two years and to 5.99 after four years at the first centre (Tullichewan): at the second centre (Ellisland) where the standard rate induced the greater vegetational response, the values were 5.17 at the commencement, 5.45 after two years and 5.81 after four years. At the first centre the lime requirement rate gave pH values 6.02 and 5.73, at the second, 5.71 and 6.16.

The Hutchinson and McLennan lime requirement at the first centre fell from 0.283 at the commencement to 0.112 after two years and to 0.126 after four years under the influence of the standard rate of treatment, while at the second centre the commencing value was 0.383, and 0.244 and 0.108 after two and four years. The total ultimate falls were therefore 0.157 and .275 respectively. From treatment at the lime requirement rate the values after two and four years were for the first centre 0.096 and 0.088, and for the second 0.211, and 0.271 thus showing ultimate falls of 0.195 and 0.112.

Considering the Hardy lime requirement figures in the same way, the first centre initially at 0.315 fell under the standard rate to 0.150 and 0.231, and the second centre initially at 0.495 fell to 0.461 and 0.371 giving ultimate falls of 0.084 and 0.124 respectively. Under the Hutchinson and McLennan lime requirement rate the Hardy figure fell at the first centre to 0.191 and 0.292; at the second centre to 0.360 and 0.218 - ultimate falls of 0.023 and 0.277.

The ultimate changes in the pH and lime requirement values may be more clearly seen in the following table.

TABLE XXXIX. RISES of pH and FALLS of Lime Requirement Values after FOUR YEARS.

Test	Rate of Liming	First Centre (Tullichewan)	Second Centre (Ellisland)
pH	Standard. L.R.	1.29 1.03	0.64 0.99
H.& McL.	Standard. L.R.	0.157 0.195	0.275 0.112
Hardy	Standard. L.R.	0.084 0.023	0.124 0.277

Considering the above figures and the botanical analyses, it appears that at each centre the plot which showed the greatest fall in the Hutchinson & McLennan lime requirement after four years, was also that on which the greatest changes in the botanical composition occurred, this being brought about on one occasion by the standard rate of treatment and on the other by the lime requirement rate. The position is otherwise in the cases of the pH and Hardy lime requirement values. The plots showing the greater botanical changes gave the smaller rises in pH values and the smaller falls in Hardy lime requirement values.

It is noticeable that in ten out of the eleven cases where comparable data are presented for soils both with and without treatment (Tables XXXIV, XXXVI, XXXVIII.) the Hardy lime requirement is greater than the Hutchinson & McLennan. On the average for the eleven cases the Hardy figure is .337 and the Hutchinson & McLennan .229. That is, the Hardy figure over all is approximately a third greater. From a general consideration of herbage changes it seems probable that this extra third would have been effective in producing a further response.

FIELD SURVEY

While the Department of Chemistry of the West of Scotland Agricultural College in association with H.M. Geological Survey were making the novel departure of accumulating data for the construction of "soil" maps (46) the opportunity for co-operation arose. The data collected, included among others, field to field determinations of the lime requirement (Hardy) and pH values ($CaCl_2$).

The major operations which extended over a considerable portion of South Ayrshire, were purely geological and chemical in nature and did not in any way deal with the flora of the area covered by the survey. It was therefore in an attempt to discover whether a relationship could be detected between the vegetation and the soil determinations that a wide field botanical survey was undertaken.

A soil survey of similar extent and intensity had not previously been carried out, therefore there were no a priori grounds for supposing that a definite connection would or would not be found between the amounts of any species and any of the chemical determinations. Past experiences tended to suggest that if relationships existed they would be loose, but these experiences were not gained under strictly analogous conditions, therefore the questions at issue were really open. Further, it was eminently desirable both from practical and theoretical considerations to have information as to whether these soil factors were sufficiently potent to be reflected in a readily measureable way on the herbage.

The soil was sampled in the usual manner with a soil auger, several cores being taken at scattered points and bulked for each field. The samples were then tested for lime requirement, pH values etc. in the chemical laboratories.

PURPOSE of SURVEY

While the present investigation was primarily concerned with the herbage, particularly the grasses, it was necessary as a preliminary to examine the soil data. Should the lime requirements and the pH values show any close relationship it would be unnecessary to consider each separately in relation to each species. The following therefore was the order in which the questions presented themselves.

The soil data were made available by the courtesy of Professor McArthur and Dr Whittles.

(1) Over this tract of country, without regard to other soil variants, do the lime requirement and the pH values of samples drawn as indicated show any relationship?

(2) Do the percentages of the principal species in old pasture vary with the lime requirement and (or) the pH values?

PROCEDURE

It was quite outwith the capacity of a single worker to undertake botanical analyses corresponding to the several thousand soil determinations which had been made as a result of team work. This however seemed unnecessary, if a suitable area were selected and a sufficient number of analyses were made to display any trends which might exist. The three main desiderata were that the area should have been soil-surveyed in as much detail as possible - not less than field to field; that as wide a range of lime requirement and pH values as possible should be shown; and that the physical character of the soil should not vary too widely.

The area chosen as combining these features in the greatest degree was that bounded on the east and west by the limits of Ordnance Survey Maps, Ayrshire, Sheets XXXV S.W. and XLI N.W. (Scale 6" to 1 mile): on the north by the Skares-Cumnock road - with the exception of a few fields north of the road, and on the south by the moorland.* In all, it extended to approximately three square miles, comprising some 66 fields.

The herbage analyses were carried out by the "Point Quadrat" method. The extent of the survey precluded more than twenty readings per field. Previous experience had shown that considerable differences might be found within comparatively short distances even where the field as a whole appeared fairly uniform. But in the present case most of the fields were obviously far from being uniform, therefore in view of the possible number of readings it was considered advisable to rely on the personal factor rather than on randomising of samples. This appeared to be eminently an instance where "common sense" had to be applied rather than hard and fast rules.

The chief disturbing factor was the presence of rush (Juncus communis, Mey.) often in considerable, and sometimes in preponderating amount. Sometimes it was present as scattered tufts, sometimes as regularly distributed tufts, sometimes as patches, large or small, and at times not tufted at all but having a more or less

* Copies of maps with boundaries marked and fields numbered, enclosed in cover pocket.

uniform growth intermingled with grasses and other plants.

The possibility of estimating the rush as a percentage of the whole, and the other species as percentages of the remainder was considered. This had actually to be done in these cases where the rush grew in solid patches to the exclusion of everything else. It was not however feasible to leave results for comparative purposes in this form, for two main reasons. Firstly, in many cases the rush growing sparsely and intermixed with grasses had to be considered as one of the components of the pasture and secondly even large patches of rush with no grass amongst them, were really colonists which had successfully ousted the grasses which had previously existed and therefore to that extent it was legitimate to reduce the percentages of these. Where the grasses etc. had to be measured apart from the rush in the first instance, the readings were made at typical but widely scattered points throughout the non-rush area.

The amounts therefore set forth in Table XL are percentages of the total herbage composing each field. Only the gramineous species with the addition of Trifolium repens and Juncus communis are dealt with here, thus summation for any one field does not give one hundred per cent. At the foot of Table XL also, are given the pH and lime requirement values for each field. The order in which the fields are numbered is simply the order in which they were analysed and is therefore of no further significance than indicating (in most cases, but not all) that consecutive numbers represent adjacent fields.

It may be noted that while the last field is numbered "66" there are in fact sixty one analyses given. The data for five fields have been omitted since these fields were either entirely covered by rush or had been re-seeded the previous year, whereas the others were either in permanent pasture or old lea.

TABLE XL. BOTANICAL ANALYSES of OLD PASTURE FIELDS

PERCENTAGE of PRINCIPAL SPECIES
with CORRESPONDING pH and LIME REQUIREMENT VALUES.

Field No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	17	18	22	23	24	25	26
Species.																						
Dactylis glomerata.	1	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	6	-
Cynosurus cristatus.	5	7	1	1	2	1	1	-	2	4	-	1	4	-	-	4	6	24	5	-	5	12
Festuca pratensis.	4	-	-	-	-	-	-	-	-	1	-	3	-	-	3	-	-	-	-	1	1	-
Festuca ovina.....	-	-	12	3	-	-	-	3	-	-	11	7	-	-	13	-	-	-	-	1	-	-
Poa spp....	6	6	-	27	1	2	-	-	1	1	-	2	3	2	-	15	2	-	2	-	20	16
Lolium perenne...	-	8	-	-	1	-	-	-	-	-	-	-	-	2	-	1	-	-	-	-	3	
Phleum pratense..	-	29	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	6	-
Agrostis spp.......	7	3	1	3	1	3	3	22	1	9	1	-	2	1	4	7	3	1	1	3	-	3
Anthoxanthum odoratum..	20	30	19	30	7	28	7	30	4	33	17	15	46	36	13	13	34	30	8	20	10	21
Holcus lanatus...	11	12	10	9	3	23	1	11	2	1	-	-	6	18	2	25	19	11	2	4	20	15
Trifolium repens....	1	-	3	6	1	7	2	5	1	4	2	1	10	6	-	11	6	5	2	4	-	2
Juncus.....	22	-	20	4	77	10	82	8	83	10	40	30	12	20	43	1	5	6	59	41	-	22
pH.........	4.39	4.53	4.57	4.48	4.43	4.46	4.57	4.34	4.66	4.41	4.59	4.48	4.38	4.45	4.60	5.02	4.82	4.66	4.79	4.41	5.02	4.70
L.R.........	.368	.255	.273	.354	.329	.315	.303	.308	.323	.302	.243	.399	.308	.380	.251	.332	.248	.287	.237	.530	.360	.305

TABLE XL. (Contd) BOTANICAL ANALYSES of OLD PASTURE FIELDS

PERCENTAGE of PRINCIPAL SPECIES
with CORRESPONDING pH and LIME REQUIREMENT VALUES

Field No.	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42S	42N	43	45	46	47	48
Species.																						
Dactylis glomerata.	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Cynosurus cristatus.	-	-	-	-	-	16	4	7	5	9	14	-	6	3	3	36	28	22	38	8	23	21
Festuca pratensis.	-	-	-	-	-	-	-	-	-	-	1	-	3	-	-	-	-	-	-	-	-	-
Festuca ovina.....	4	2	4	2	1	9	7	1	-	9	8	8	9	1	2	-	-	3	-	-	1	-
Poa spp....	-	-	1	2	1	-	23	29	5	9	31	-	17	9	4	-	8	9	4	2	-	6
Lolium perenne...	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	2	7	2	20	-	12
Phleum pratense..	-	-	-	-	-	-	-	-	5	-	3	-	2	-	-	-	-	-	-	2	-	-
Agrostis spp.......	-	-	-	-	-	2	4	4	2	15	-	-	10	-	-	-	-	-	-	-	2	-
Anthoxanthum odoratum..	5	1	2	2	3	33	17	13	25	21	10	1	12	33	15	30	26	30	20	22	21	21
Holcus lanatus...	-	1	1	2	-	7	17	15	3	13	18	-	22	11	8	6	18	9	14	12	12	5
Trifolium repens....	2	1	-	-	-	6	5	10	20	2	-	-	-	2	2	6	8	4	8	16	9	7
Juncus.....	85	87	90	89	95	1	5	3	25	9	5	39	5	14	42	4	-	1	4	-	7	-
pH.........	4.93	4.72	4.48	4.48	4.69	5.07	5.11	4.90	4.64	4.19	4.69	4.19	4.26	4.05	4.55	4.77	5.17	4.88	5.35	5.00	4.43	4.76
L.R.........	.309	.308	.608	.608	.473	.246	.458	.270	.413	.504	.590	.504	.750	.860	.750	.276	.186	.342	.210	.302	.303	.147

TABLE XL. (Contd) BOTANICAL ANALYSES of OLD PASTURE FIELDS

PERCENTAGE of PRINCIPAL SPECIES
with CORRESPONDING pH and LIME REQUIREMENT VALUES.

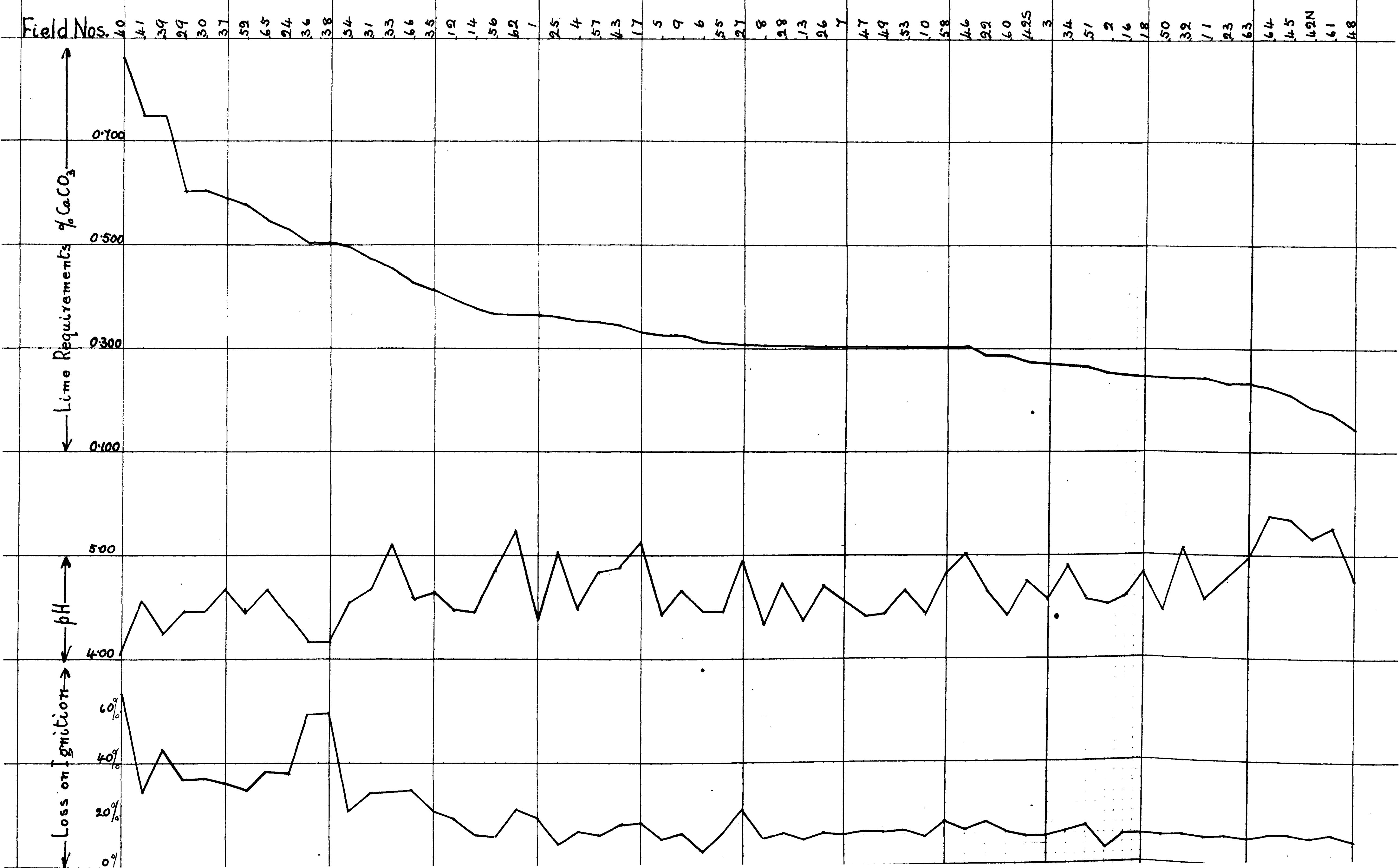
Field No.	49	50	51	52	53	54	55	56	57	58	60	61	62	63	64	65	66
Species.																	
Dactylis glomerata...	-	-	-	2	-	-	-	-	-	-	-	-	4	-	-	-	-
Cynosurus cristatus...	5	20	13	5	20	4	5	18	2	12	30	30	5	22	22	15	18
Festuca pratensis...	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
Festuca ovina	-	-	-	-	-	1	2	-	-	-	-	-	1	-	4	-	1
Poa spp......	7	10	17	-	-	15	2	6	9	8	12	35	12	8	2	3	4
Lolium perenne	9	8	4	18	4	4	10	10	2	9	10	5	5	12	11	5	9
Phleum pratense....	16	-	11	7	-	9	-	3	-	3	-	-	10	1	-	5	12
Agrostis spp.	-	-	-	-	20	-	-	-	-	1	-	-	-	-	-	-	-
Anthoxanthum odoratum....	26	17	21	11	20	33	25	16	21	11	2	-	13	17	25	29	20
Holcus lanatus	14	9	12	8	9	13	11	10	7	5	2	5	6	12	15	5	4
Trifolium repens......	1	6	-	13	1	-	4	5	1	4	30	15	-	7	3	-	5
Juncus.......	3	6	4	2	9	3	9	5	22	5	2	-	-	4	4	3	-
pH..........	4.43	4.46	4. 59	4.46	4.66	4.57	4.46	4.85	4.81	4.81	4.41	5.26	5.24	4.97	5.38	4.69	4.60
L.R..........	.303	.248	.264	.578	.303	.495	.311	.369	.353	.302	.285	.173	.368	.237	.222	.548	.429

To deal with the figures more easily, cards were prepared - one for each field - on which were entered the percentage of each species, the lime requirement and the pH values and the loss on ignition. The cards were then arranged in descending order of lime requirements. In this order the lime requirements, the pH values and the loss on ignition were plotted to bring out any relationship which might exist between them.

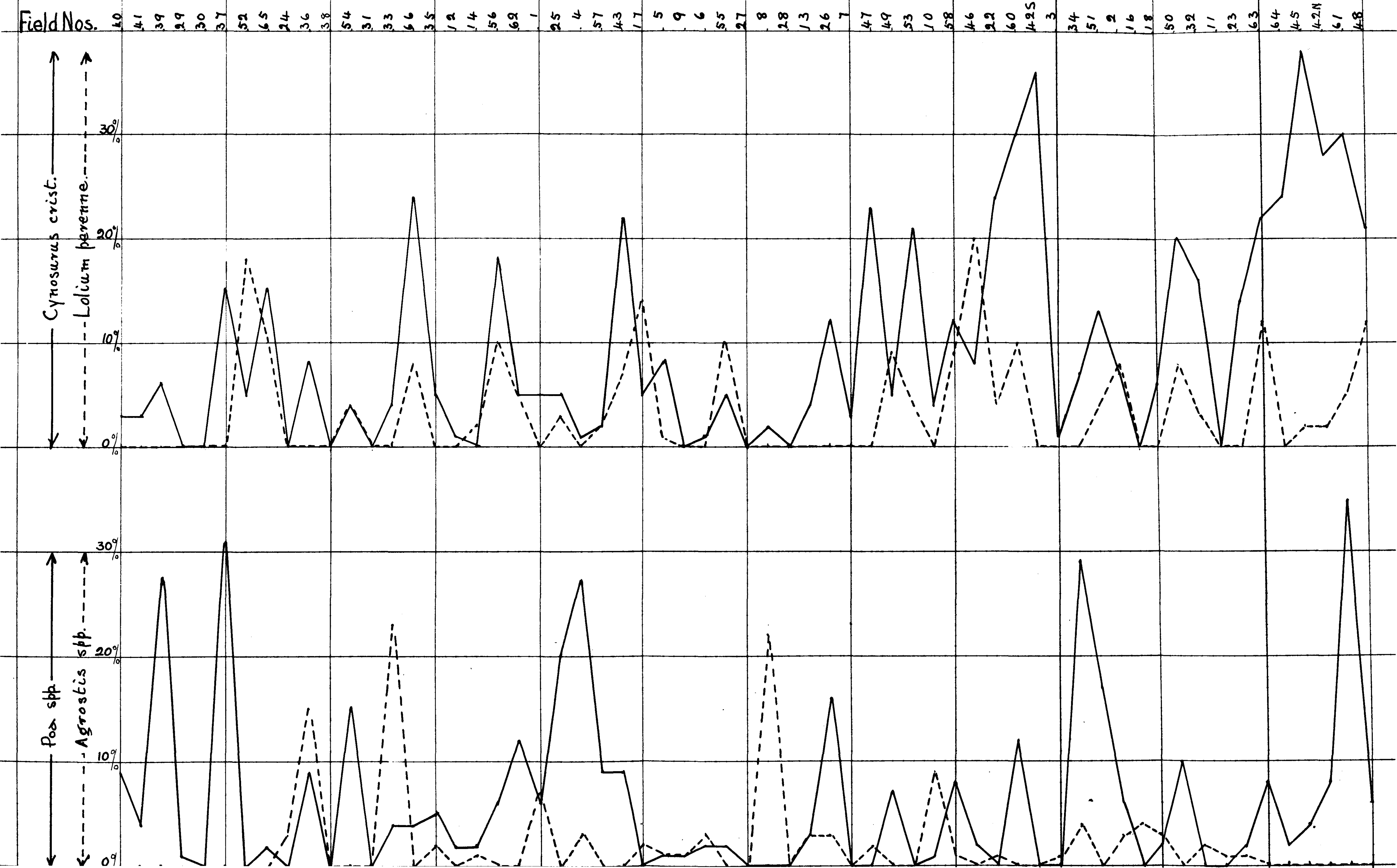
As may be seen from Graph 1 there is a tendency over the whole series for these values to move simultaneously. As the lime requirement falls the general trend of the pH values is upwards. It is, however, only a general trend, the individual values being very erratic. With a falling lime requirement there is a general fall in organic matter. (The organic matter content is of course a partial cause, more than an effect.) But as the organic matter content is so uniform throughout the area the parallelism between it and the lime requirement is only seen in the first half of the graph.

Of the twelve species dealt with in Table XL. only in the cases of eight were relationships sought with the lime requirement and pH values, the other four being of less frequent occurrence. Lolium perenne and Agrostis

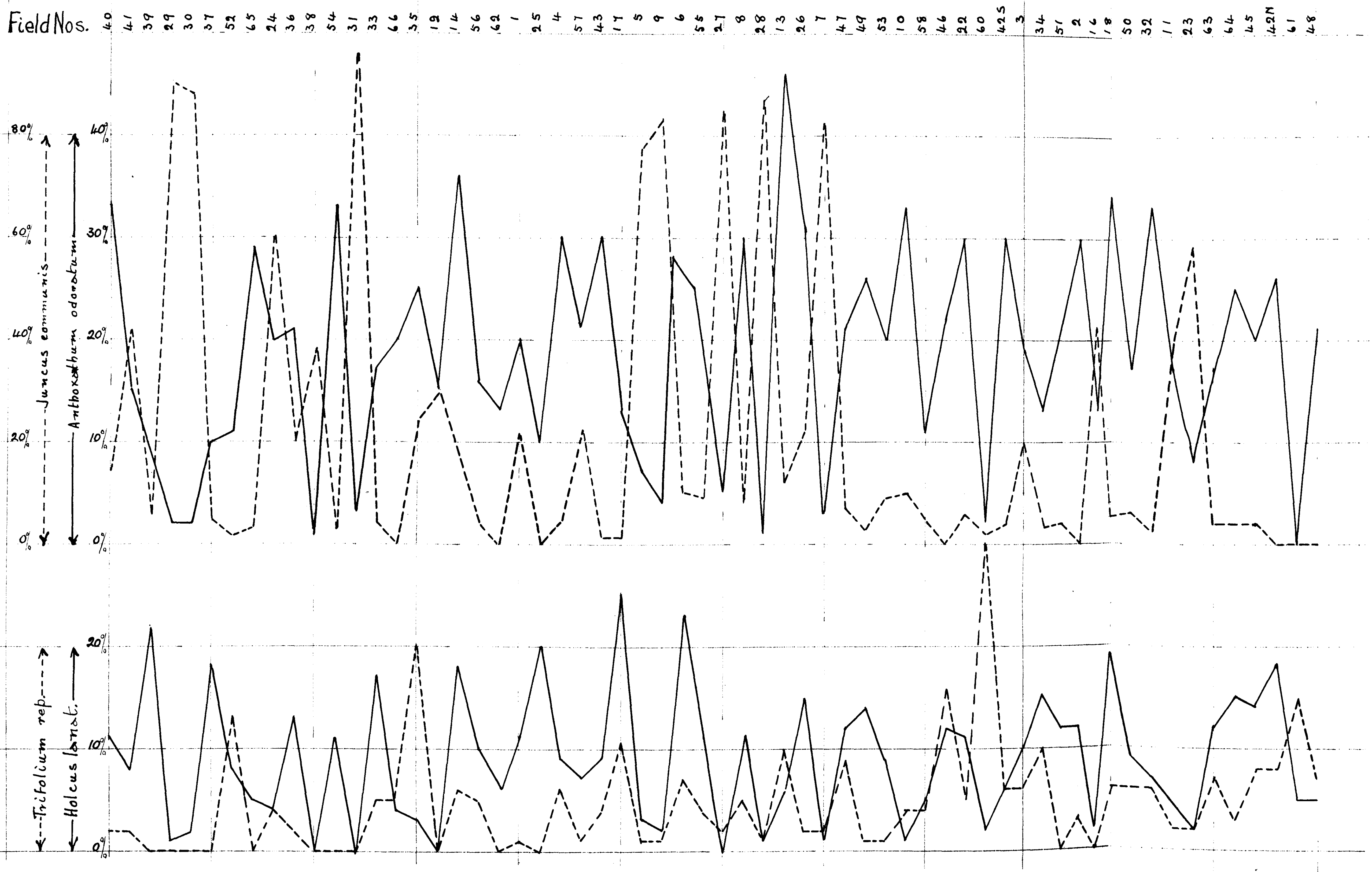
Graph 1. Lime Requirements in Descending Order, with Corresponding pH values and Loss on Ignition.



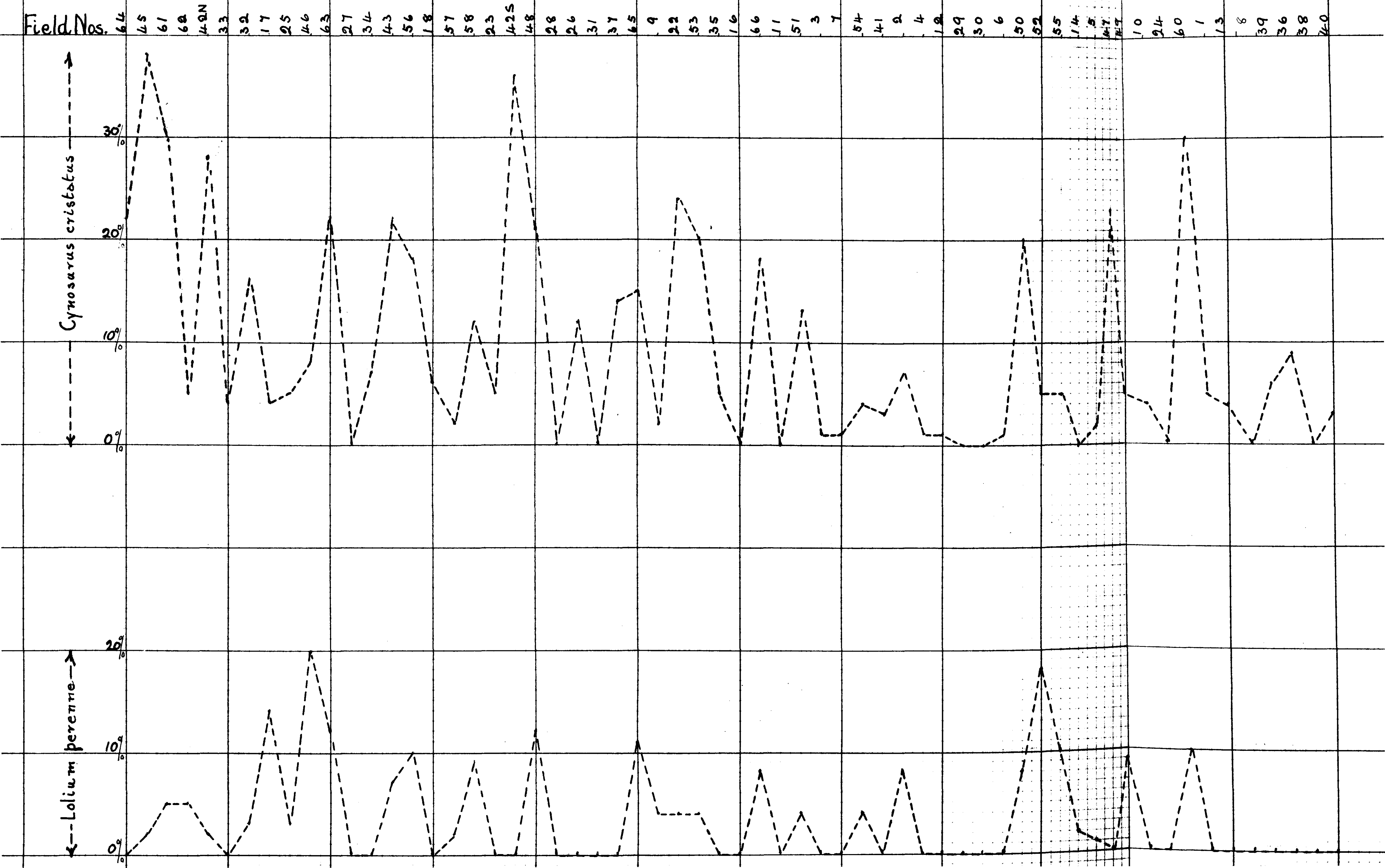
Graph 2. Percentages of Cynosurus cristatus, Lolium perenne, Poa spp., and Agrostis spp. in Order of Descending Lime Requirements.



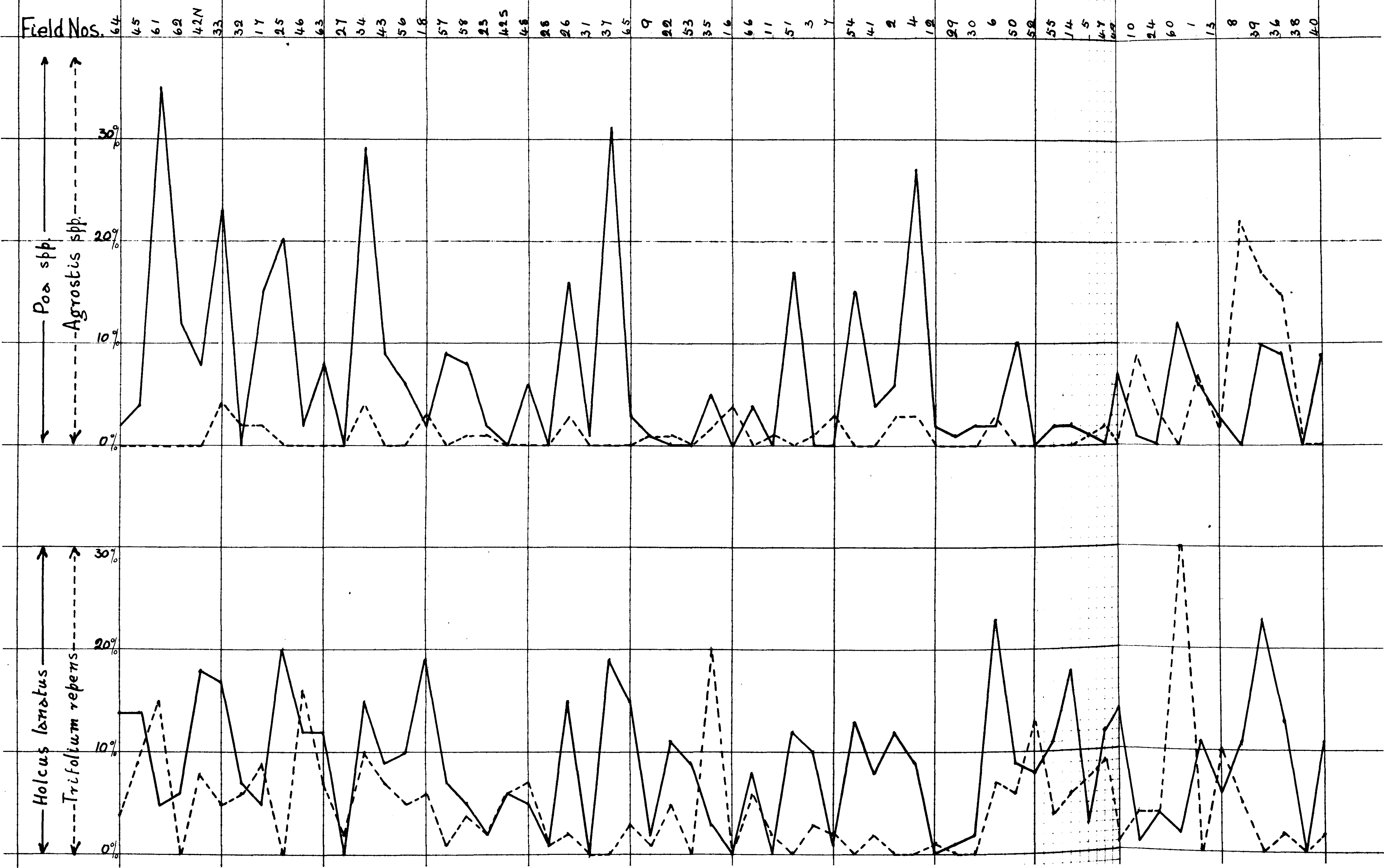
Graph 3. Percentages of Anthoxanthum odoratum, Juncus communis, Holcus lanatus & Trifolium repens in Order of Descending Lime Requirements.



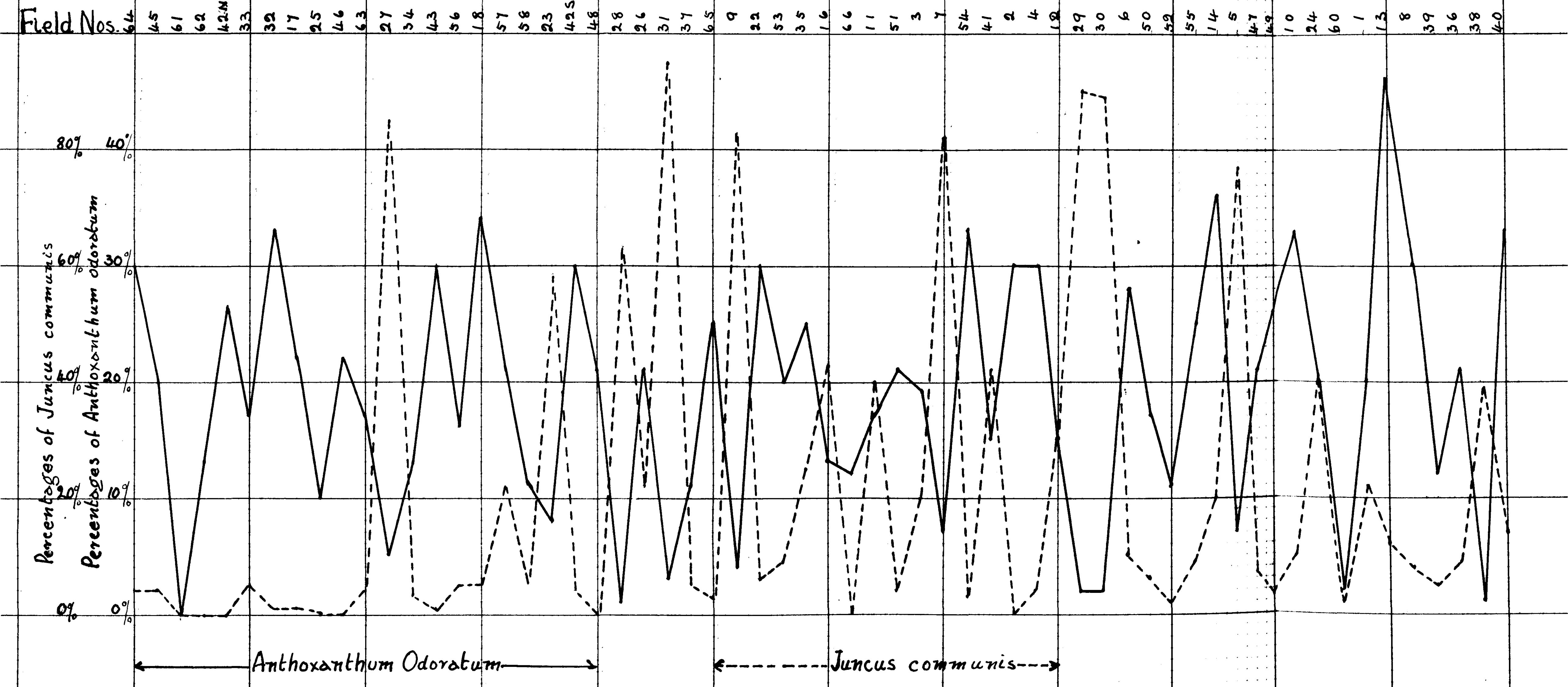
Graph 4. Percentages of Cynosurus cristatus and Lolium perenne in Order of Descending pH values.



Graph 5. Percentages of Poa spp., Agrostis spp., Holcus lanatus & Trifolium repens in Order of Descending pH values.



Graph 6. Percentages of Anthoxanthum odoratum and Juncus communis in Order of Descending pH values



were often absent but these were retained for consideration since in other investigations they had been found to be influenced by the lime status of the soil.

To find whether the percentage of any species rose or fell with the lime requirement of the soil on which it was growing, the following procedure was adopted. At equal intervals along a horizontal axis were placed the reference numbers of the fields in order of decreasing lime requirement. From a perpendicular scale the percentage of each species was plotted. The points marking the percentage on each field were then joined by straight lines. A positive correlation would thus be indicated by a fall in the graph from left to right.

Graph 2 shows the cases of Cynosurus cristatus, Lolium perenne, Poa and Agrostis; graph 3 of Anthoxanthum odoratum, Juncus communis, Holcus lanatus and Trifolium repens.

These graphs give no evidence of correlation between the percentage of any species and the lime requirement.

Now, although there was a slight tendency for the pH values to rise as the lime requirements fell, the correlation was not sufficiently high to justify the conclusion that the percentages of the species were no more closely correlated with the pH than with the lime requirement values. The same method as before was taken therefore to show whether this were so or not. In this case the reference numbers of the fields in order of decreasing pH value were placed at equal intervals along a horizontal axis, and a graph falling from left to right would indicate a positive correlation. Graph 4 shows the results for Cynosurus cristatus and Lolium perenne; graph 5 for Poa, Agrostis, Holcus lanatus and Trifolium repens; graph 6 for Anthoxanthum odoratum and Juncus communis.

DISCUSSION

If any extensive area is to be surveyed for the collection of soil and botanical data, considerable distances must intervene between the points from which successive soil samples are drawn and also between those where successive botanical readings are made. The attempt was made to average out small local differences by taking four or five sub-samples and bulking these to give a soil sample representative of a few acres (more or less according as the soil appeared to change in character).

Similarly for each area represented by a complete soil sample, twenty "Point Quadrat" readings were made, summed and divided by two to give the percentage botanical analysis. The soil sampling and the botanical analyses were not done at the same time and therefore it would have been pure coincidence had a sample been drawn from exactly the same point at which a botanical reading was made.

From soil samples drawn, and botanical analyses made as indicated, the search for a correlation between the lime requirements and the percentage of the commoner species yielded entirely negative results. Similar results for the most part were obtained in seeking a correlation between the percentages of the species and the pH values. There was however in this case a suggestion that Cynosurus cristatus and Poa spp. (mainly trivialis) tended to be present in smaller amounts as the acidity increased. Likewise there was a suggestion, though faint, that Agrostis, became more prevalent with an increase in acidity.

LATIN SQUARE EXPERIMENT

One of the great weaknesses in most experiments designed to test the effect of this or that treatment is that as a result of insufficient replication and lack of proper arrangement of the plots, the results are not susceptible of statistical treatment. Their significance therefore cannot be properly assessed. To allow for this it was resolved to conduct an experiment in which the plots were arranged on the "Latin Square" system, to the results of which the analysis of variance as developed by Fisher (16) might be applied.

This procedure seemed desirable not only from the interest which might accrue from the immediate results but also from the fact that such a method of experimentation had never before been tried in the West of Scotland and so far as could be learned had not previously been applied at any centre to the problem under consideration.

While the experiment was conceived and designed to last for an indefinite number of years, its immediate objects were to supply accurate information to the following questions:-

(1) Does a small area (0.4 acres) of apparently uniform soil possess from point to point any considerable variation in (a) acidity as indicated by the pH values, and (b) need for lime as indicated by the "Lime

"lime requirement" figures?

(2) If variation does occur is there any apparent relationship between the pH values and the lime requirement figures?

(3) To what extent does the botanical composition of old pasture show variation throughout a small area?

(4) If a range of pH and lime requirement values is found, will the botanical composition show any relationship to that of either the pH or lime requirement values within a small area?

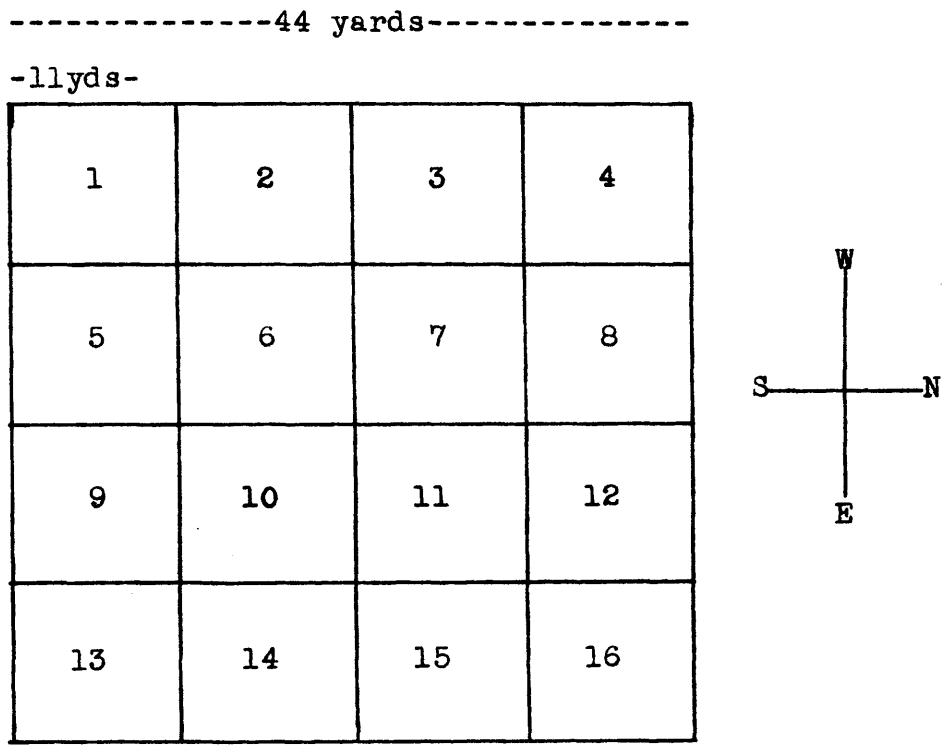
(5) What effect on the yield of old pasture have increasing applications of calcium carbonate based on the lime requirement rate?

PROCEDURE.

Laying off the Plots.

Facilities for the carrying out of the experiment were afforded by the Plant Husbandry Department of the West of Scotland Agricultural College, in the grounds at Auchincruive, Ayr. From a twelve acre field of old pasture which had not been ploughed for at least twenty years and which had been subject to mixed grazing by cattle and sheep, an apparently uniform area was selected. A square of 44 yards side was measured off and this was divided into 16 equal plots. The total area and the area of each plot was therefore $\frac{4}{10}$ acre and $\frac{1}{40}$ acre respectively. The plots were numbered as indicated in the following plan.

PLAN showing LAYOUT of PLOTS



PRELIMINARY SAMPLING

In order to find in the first instance whether the soil did vary from plot to plot in its pH value and lime requirement and so determine the future course of action, preliminary small samples of soil and subsoil were taken from each plot by means of a soil auger. On testing it was found that for the soil the pH values ranged from 4.29 to 5.11 and the lime requirement figures from .160 to .262 per cent calcium carbonate. The values for the subsoil showed a slightly greater range.[x]

BULK SAMPLING.

The figures obtained from the preliminary samples were considered to show sufficient fluctuation to justify the re-taking of samples which would more closely reflect the character of each plot considered as a unit. Further, it was resolved that the samples should be of sufficient size to afford a large surplus after the tests had been carried out. This precaution was taken so that any reading could be checked later and, since it was proposed to leave the experiment down for an indefinite number of years, the original soils and subsoils would still be available should any new tests be devised. Accordingly cores of soil and subsoil were taken at yard intervals throughout each plot and bulked separately, giving sixteen composite samples of soil and sixteen of subsoil. The laborious process of drawing some sixteen hundred cores of soil and an equal number of subsoil was unavoidable in obtaining the desired accuracy of representation. The result is however that there now exists information on the soils which has not

x The complete values for the preliminary and bulk samples are recorded in Appendix B.

before been available in such detail as a basis for field experimentation.

TABLE XLI. pH and LIME REQUIREMENT VALUES of soils from 16 PLOTS.

Plot No.	pH	Lime requirement % $CaCO_3$
1	4.81	0.274
2	4.91	0.249
3	5.23	0.277
4	5.24	0.270
5	5.02	0.252
6	4.85	0.255
7	4.95	0.255
8	4.93	0.255
9	4.70	0.278
10	4.95	0.248
11	4.95	0.290
12	5.59	0.278
13	4.62	0.263
14	4.75	0.276
15	4.90	0.285
16	5.31	0.300

Although a transition in the nature of the soil from plot to plot was not obvious from inspection it was thought possible that the pH or lime requirement figures might show a trend in some particular direction. In order to display whether this were so or not the figures were arranged in the same relative positions as the plots, giving as it were plans of pH and lime requirement values:-

TABLE/

TABLE XLII. PLAN of pH VALUES

(Plot Nos. in Brackets)

(1) 4.81	(2) 4.91	(3) 5.23	(4) 5.24
(5) 5.02	(6) 4.85	(7) 4.95	(8) 4.93
(9) 4.70	(10) 4.95	(11) 4.95	(12) 5.59
(13) 4.62	(14) 4.75	(15) 4.90	(16) 5.31

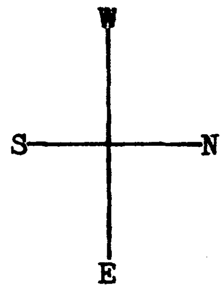


TABLE XLIII. PLAN of LIME REQUIREMENTS

(Plot Nos. in Brackets)

(1) .274	(2) .249	(3) .277	(4) .270
(5) .252	(6) .255	(7) .255	(8) .255
(9) .278	(10) .248	(11) .290	(12) .278
(13) .263	(14) .276	(15) .285	(16) .300

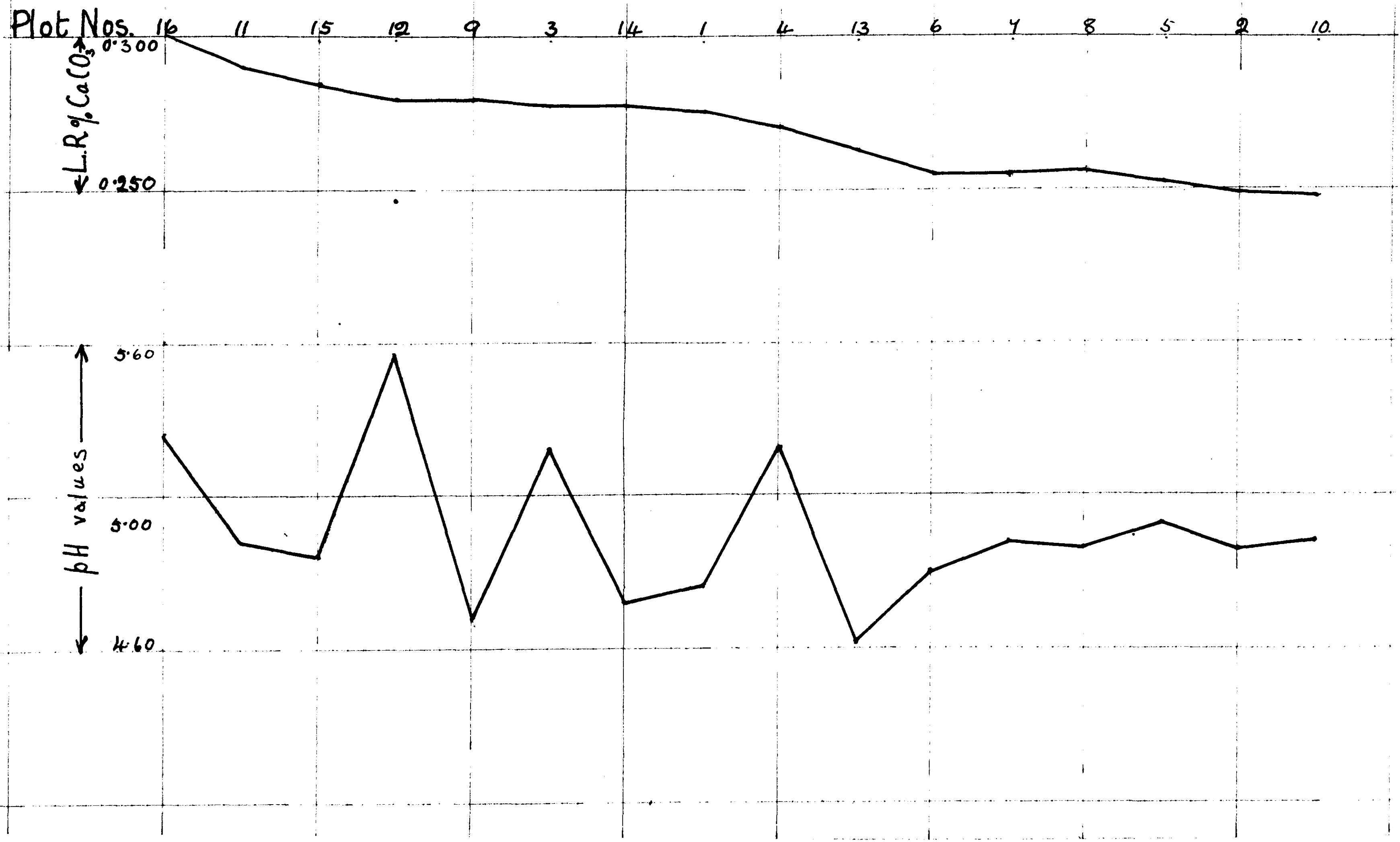
It will be seen from Table XLII that the pH values show no consistent rise or fall from West to East. There is however a general tendency to rise from South to North with a persistent rise from South West to North East along the strip occupied by Plots (1), (6), (11), (16) and (2), (7), (12): and from South East to North

West along the strip occupied by Plots (13), (10), (7), (4) and (9), (6), (3). The lime requirement figures show much irregularity and the only persistent trend is a rise from South to North along the plots (13), (14), (15) and (16).

While inspection of Tables XLII and XLIII strongly suggest an absence of correlation between the pH value and the corresponding lime requirement figures, a graphical method has been employed to display these readings so that any relationship which may have escaped notice on inspection of the figures will be brought out. The Plot numbers, arranged in order of decreasing lime requirements, have been placed at equal intervals along the horizontal axis while on the vertical a scale represents lime requirements. The appropriate lime requirement figure for each plot was marked by a point. The points were joined to give a continuously falling graph. Using the same horizontal scale but a new vertical scale of pH values, the pH readings were graphed in a similar way. (Graph 7).

It is clear from the graph that within the limits of the observations in this experiment no correlation exists between the lime requirement figures and the pH values.

Graph 7. Lime Requirements in Descending Order, with Corresponding pH values.



BOTANICAL ANALYSES

The botanical analyses of the plots were made by the "Point Quadrat" method. For each plot two groups of ten readings were made - one group along each diagonal, the individual readings being taken at intervals of approximately one and a half yards. The percentage compositions arrived at by the separate summations of the groups for each plot agreed so well in the majority of cases that it seemed clear that for more extensive studies where time was an important factor, single groups of ten readings would yield results of considerable value. In this particular instance however the two percentages for each plot were averaged to obtain greater accuracy. The analyses thus arrived at are given in Table XLIV.

TABLE XLIV.

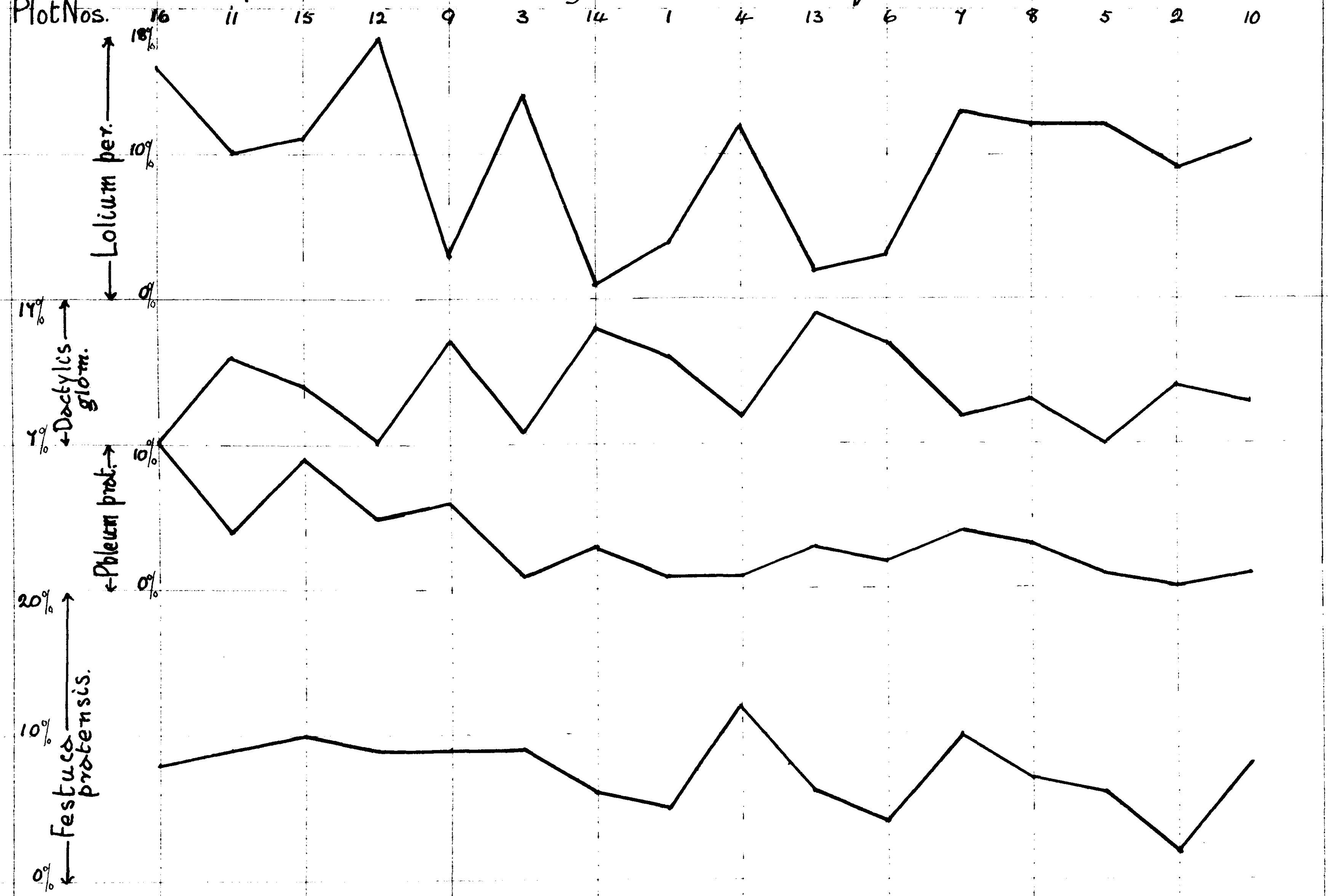
BOTANICAL ANALYSES of PASTURE PLOTS

Plot Nos.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Species																
Lolium perenne,L....	4	9	14	12	12	3	13	12	3	11	10	18	2	1	11	16
Dactylis glomerata,L	13	11	8	9	7	14	9	10	14	10	13	7	16	15	11	7
Phleum pratense,L...	1	-	1	1	1	2	4	3	6	1	3	5	3	3	9	10
Festuca pratensis, Hackel............	5	2	9	12	6	4	10	7	9	8	9	9	6	6	10	8
Cynosurus cristatus, L................	13	10	6	7	9	13	7	11	17	10	13	6	16	14	11	8
Poa trivialis,L.....	21	11	14	26	12	12	15	23	12	20	18	12	15	25	24	27
Agrostis vulgaris, With.	24	31	31	14	23	32	26	8	20	25	12	9	18	18	7	6
Holcus lanatus,L....	11	21	12	16	19	14	13	20	11	14	21	25	20	15	14	15
Festuca rubra,L.....	3	1	1	-	-	3	1	1	3	-	-	-	-	-	-	-
Anthoxanthum odoratum,L............	1	1	2	1	2	1	1	-	1	-	-	4	2	2	1	1
Cnicus arvensis, Hoffm.	1	1	-	-	1	1	1	3	1	-	1	2	-	1	-	-
Ranunculus spp......	2	1	2	2	5	1	-	2	2	1	-	2	1	-	2	1

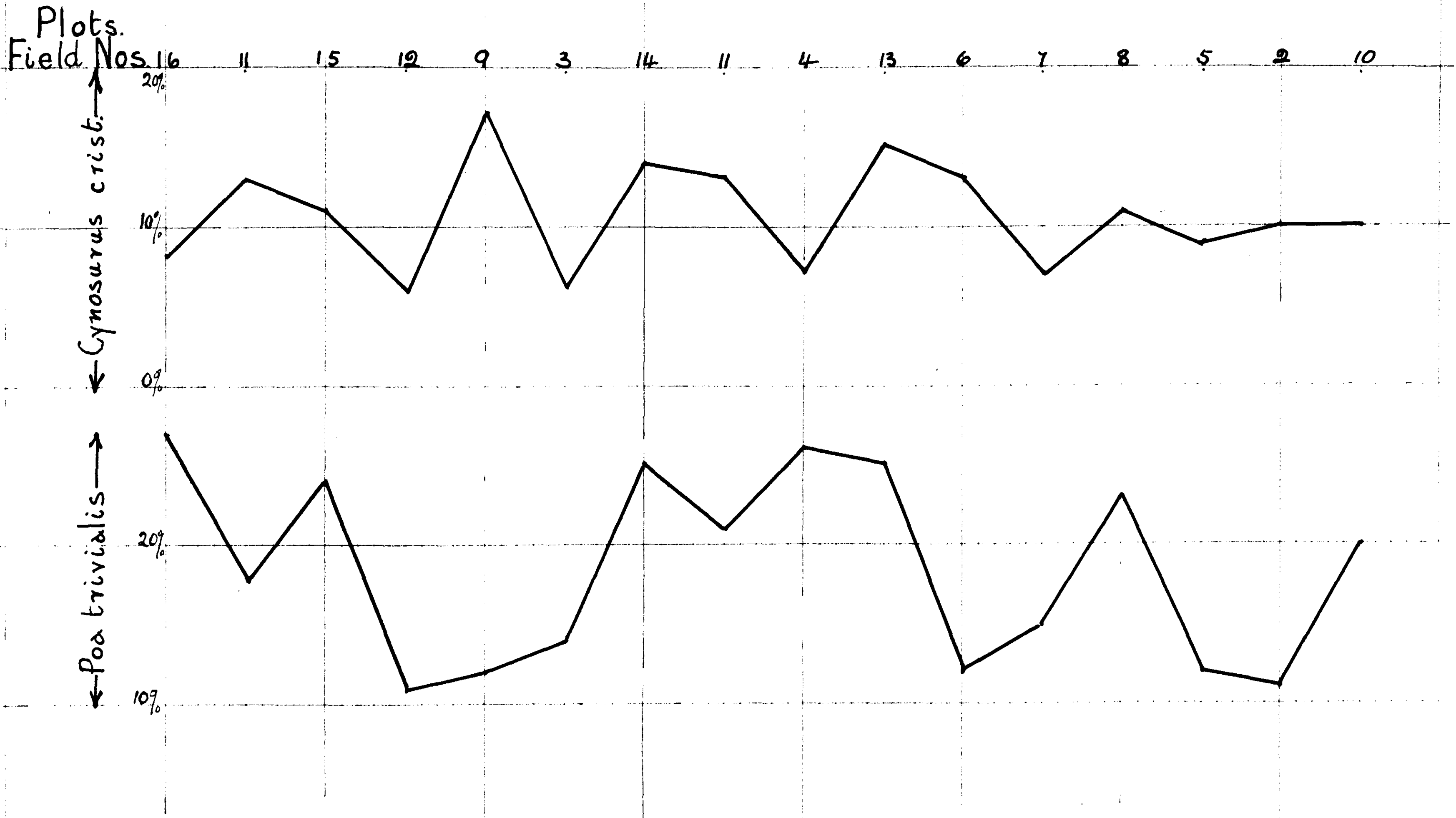
The table shows that there were eight principal species contributing to the pasture and four which occurred fairly frequently but did not make any large contribution. A few scattered plants of Trifolium repens, Rumex acetosa, Plantago lanceolata, Alopecurus geniculatus, and Luzula campestris were found and on one plot (No.16) there was a very faint trace of Juncus.

In order to ascertain whether any connection existed between the percentages of the principal components of the pasture and the lime requirement of the soil, the percentages for each species were graphed against the Plot numbers arranged in decreasing order of lime requirement (see Graph 7). Should a particular species be present in greater abundance where the soil shows less need for lime then the graph will rise from left to right: should the species be more successful where the lime requirement is high then the graph will tend to fall from left to right. Graph (8) shows the cases of Lolium perenne, Dactylis glomerata, Phleum pratense and Festuca pratensis; Graph (9) Cynosurus cristatus and Poa trivialis; Graph (10), Agrostis vulgaris and Holcus lanatus.

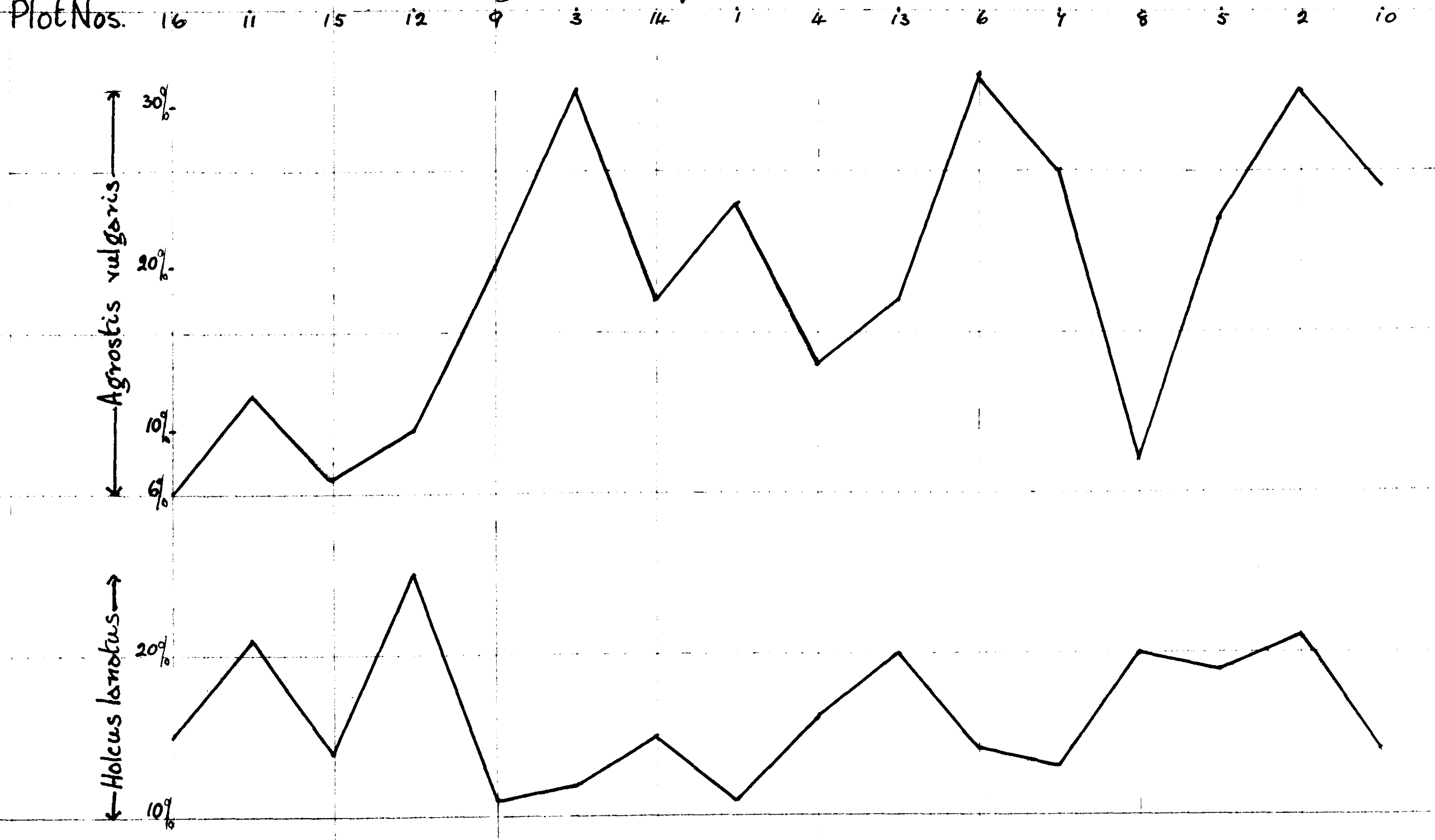
It is obvious from these graphs that there is no well defined trend in the amount of any species, Graph 8. Percentages of Lolium perenne, Dactylis glomerata, Phleum pratense & Festuca pratensis in Descending Order of Lime Requirements.



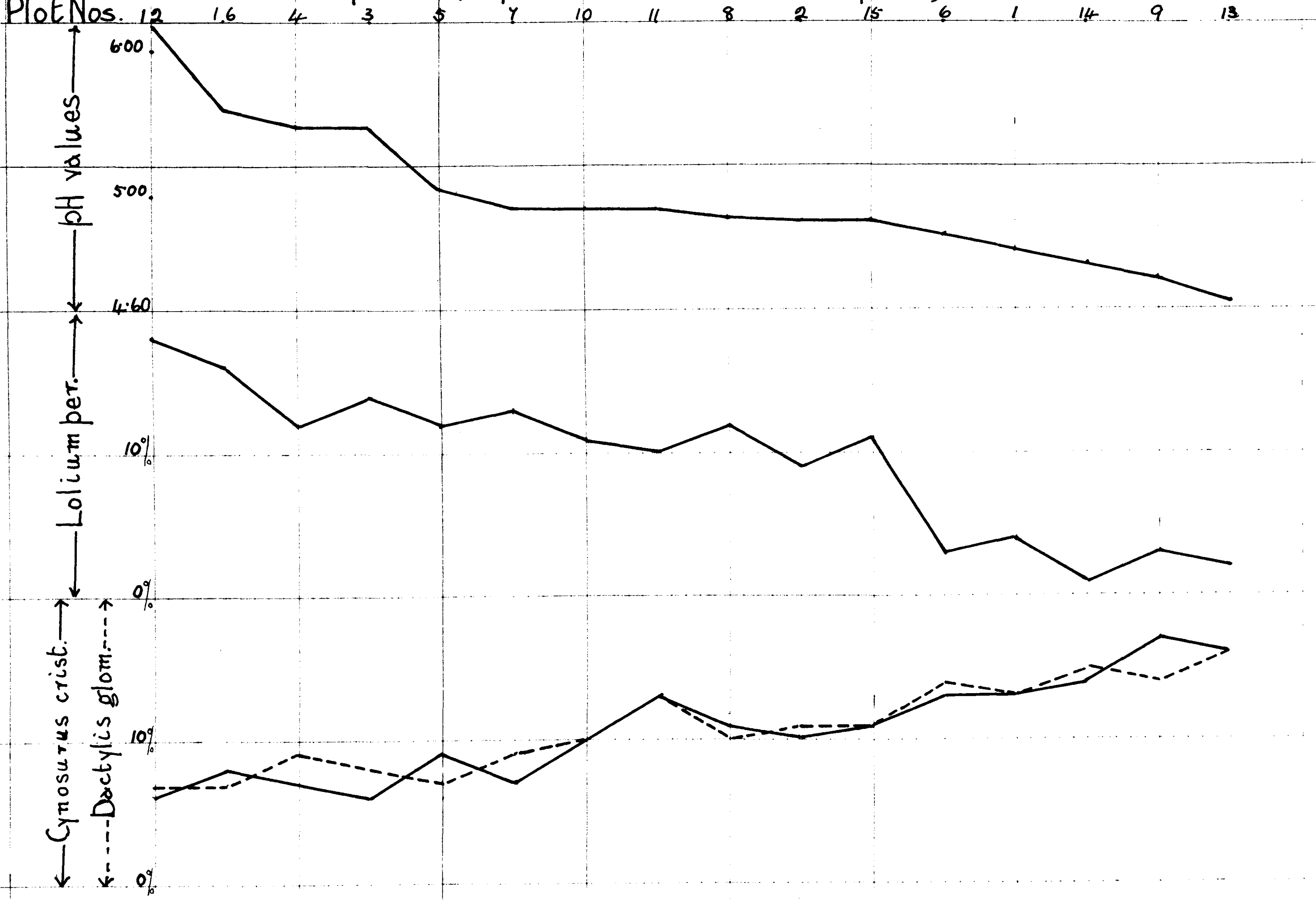
Graph 9. Percentages of Cynosurus cristatus & Poa trivialis in Order of Descending Lime Requirements.



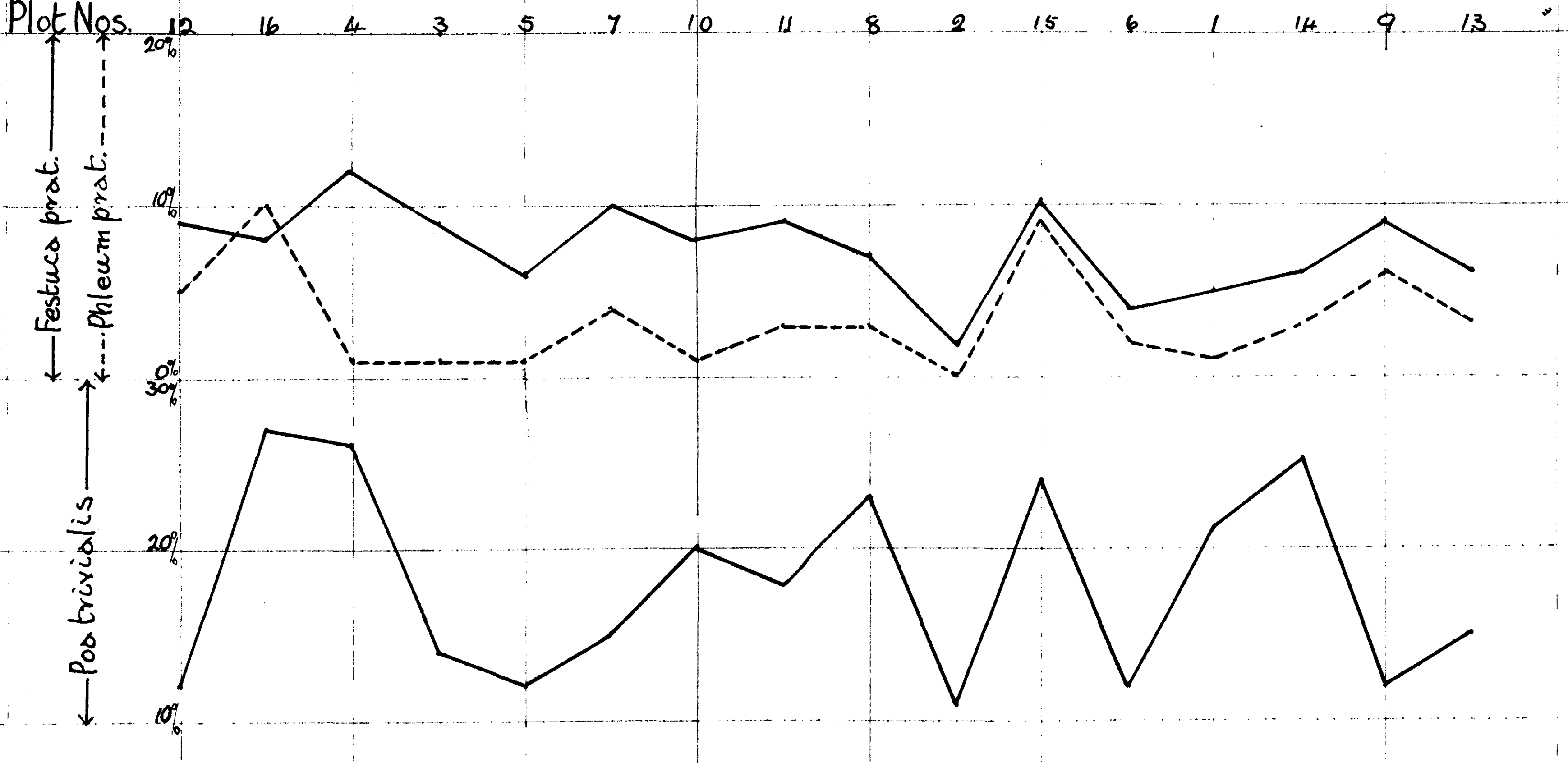
Graph 10. Percentages of Agrostis vulgaris & Holcus lanatus in Order of Descending Lime Requirements



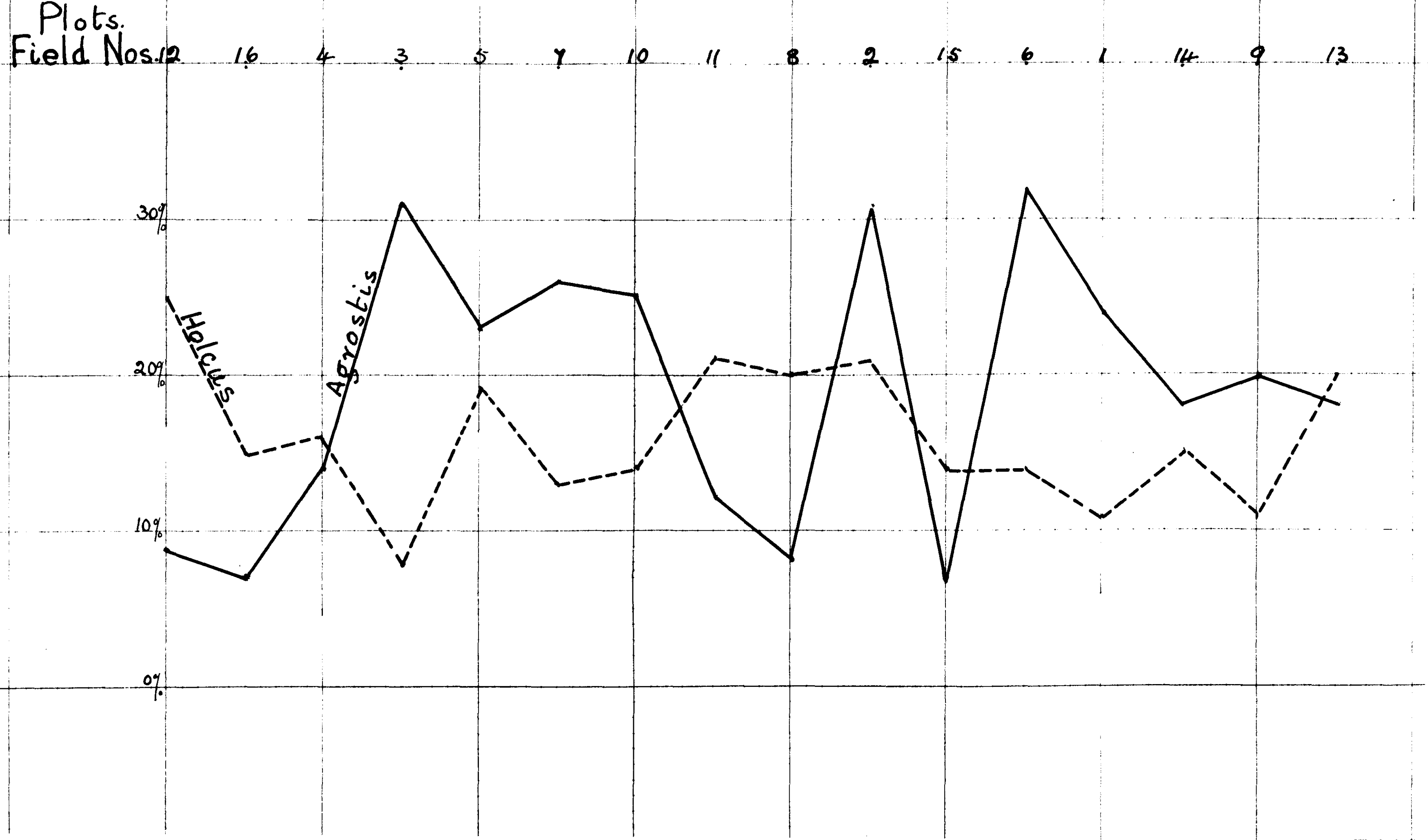
Graph 11. pH values in Descending Order, with Corresponding Percentages of Lolium perenne, Cynosurus cristatus & Dactylis glomerata.



Graph 12. Percentages of *Festuca pratensis*, *Phleum pratense* & *Poa trivialis* in Order of Descending pH values.



Graph 13. Percentages of Holcus lanatus & Agrostis vulgaris in Order of Descending pH values.



either against or with the lime requirement of the soil. Had a correlation been seen to exist between the lime requirement and the percentage of any species then obviously it would have been unnecessary to look for any between that species and the pH values. No such correlations were found therefore there still remained the possibility of a relationship between any of the species and the pH values. The same means as before were adopted to test this possibility. The plot numbers were arranged in descending order of pH value and the points marking the respective pH values joined to give a steadily falling graph. The percentages of the eight principal species were then graphed in the same order. Graphs (11), (12) and (13) show the results.

Certain interesting trends have been brought out by this arrangement, which will be discussed after all the available data from this experiment have been presented.

EFFECT of LIME on YIELD.

In order to test the effect of lime on the yield of old pasture, ground limestone containing 85.3% pure calcium carbonate was used. It was decided to apply the lime at four rates, so that each treatment could have four replicates. The rates were:-

(1) No lime - control.

(2) Half the lime requirement rate.

(3) The lime requirement rate.

(4) Twice the lime requirement rate.

Since a range of lime requirements were found, strict adherence to the original intention of liming in multiples of the plot requirements was quite impracticable moreover the statistical method (16) of dealing with the results rendered this unnecessary* since it has been designed to meet just such difficulties. Accordingly for liming purposes the mean of the sixteen plot lime requirements - .269% calcium carbonate - was taken as the unit rate of application. Thus the four rates were:-

(1) No lime.

(2) .134% calcium carbonate.

(3) .269% calcium carbonate.

(4) .538% calcium carbonate.

The weights of limestone necessary to supply these amounts of calcium carbonate were calculated from the percentage purity of the limestone.

* This is true so far as immediate results are concerned though it renders future soil reaction studies more complicated.

In order to allow of the results being analysed statistically the selection of the particular plots to receive the various treatments was purely at random with the restriction that no treatment was duplicated in the same row or column. The selection fell out as indicated in the following plan in which L.R. signifies lime requirement.

PLAN of RANDOMISED TREATMENT of PLOTS.

(Plot Nos. in Brackets)

(1) 2 L.R.	(2) Control	(3) ½ L.R.	(4) 1 L.R.
(5) 1 L.R.	(6) ½ L.R.	(7) Control	(8) 2 L.R.
(9) ½ L.R.	(10) 2 L.R.	(11) 1 L.R.	(12) Control
(13) Control	(14) 1 L.R.	(15) 2 L.R.	(16) ½ L.R.

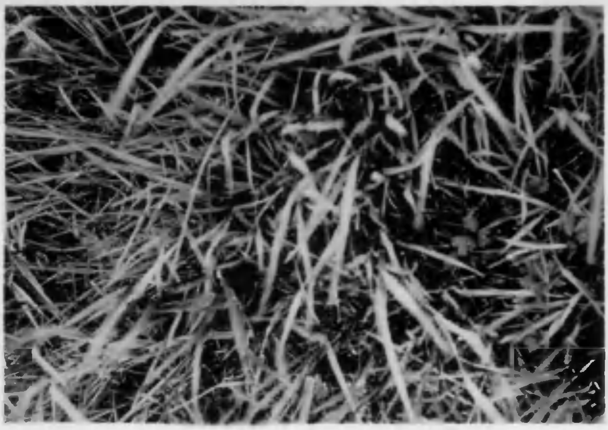
The lime was applied in mid-winter when there was very little vegetation on the plots and was harrowed in with a small spike-toothed harrow specially constructed for haulage by "man-power" on experimental plots. Subsequent heavy rains soon washed the lime into the soil

Photograph 22.

Latin Square, Plot 12. Typical open "sole" in absence of lime.

Photograph 23.

Latin Square, Plot 8. Typical dense "sole" resulting from liming. Note: Plots 12 & 8 are adjacent.



and within a few weeks none was visible on the surface except on a very few small patches.

Growth in the early part of the year was slow owing to a period of cold winds but later came away rapidly. It was obvious from inspection that considerable differences in yields would be obtained - not on account of any prominent change in the composition of the herbage, the time being too short for that, but because of the more profuse and bushy growth, giving on the heavily limed plots a thicker "sole" than on the controls. (See Photographs 22 and 23).

Five months after the application of the lime the plots were cut and weighed immediately. The weights recorded are given in Table XLV.

TABLE XLV. GREEN WEIGHTS from LIMED PLOTS.

Plot No.	lbs
1	355
2	305
3	338
4	364
5	318
6	282
7	284
8	382
9	291
10	308
11	357
12	283
13	256
14	268
15	398
16	365

In order to apply the "Analysis of Variance" so that the Standard Error of the results might be found the following was the procedure:-

(1) The mean of the sixteen plot yields was found. The squares of the deviations from this mean were summed giving 28050.75 lbs.

(2) The yields from the four treatments were summed separately. The four deviations from the mean of the four "treatment yields" were squared, summed and divided by 4, giving 12532.25 lbs.

(3) The yields from the four columns were summed separately. The four deviations from the mean of the four "column yields" were squared, summed and divided by 4, giving 9101.25 lbs.

(4) The yields from the four rows were summed separately. The four deviations from the mean of the four "row yields" were squared, summed and divided by 4, giving 2090.25 lbs.

(5) The sum of the 16 squared deviations less those for treatments, columns and rows give that for the "Error".

These figures are tabulated below -

TABLE XLVI. ANALYSIS of VARIANCE.

	Degrees of Freedom	Sums of Squares	Mean Square
Treatments	3	12532.25	
Columns	3	9101.25	
Rows	3	2090.25	
Error	6	4327.00	721.17
Total	15	28050.75	

Standard Error (4 plot totals) $= \sqrt{721.17 \times 4}$

$= \sqrt{2884.68}$

$= 53.71.$

The yields per $^1/_{10}$th acre from the four treatments, with the mean yield and the Standard Error, in lbs and as a percentage of the mean are given in Table XLVII.

TABLE XLVII. YIELDS from LIME TREATMENTS

Treatments	Control	½ L.R.	1 L.R.	2 L.R.	Mean	S.E.
lbs per 1/10 acre.	1128	1276	1307	1443	1288.5	53.71
per cent...	87.5	99.0	101.4	111.9	100	4.1

SIGNIFICANCE of RESULTS.

The significance of differences is assessed on the number of times which they exceed the Standard Error. In this type of work it is usually agreed that twice the Standard Error gives a sufficiently high probability that the differences are significant and due to treatments rather than chance.

S.E. = 4.1%
2 S.E. = 8.2%.

(½ L.R.yield) - (control yield) = 99.0% - 87.5% = 11.5%
(1 L.R. yield) - (control yield) = 101.4% - 87.5% = 13.9%
(2 L.R.yield) - (control yield) = 111.9% - 87.5% = 24.4%
(1 L.R.yield) - (½ L.R. yield) = 101.4% - 99.0% = 2.4%
(2L.R.yield) - (½ L.R. yield) -= 111.9% - 99.0% = 12.9%
(2 L.R. yield)- (1 L.R. yield) = 111.9% - 101.4% = 10.5%.

It will be seen that all those differences with the exception of that between the yields from the lime requirement rate and the half lime requirement rate are significant.

DISCUSSION of RESULTS of LATIN SQUARE EXPERIMENT.

Soil surveys in the past have generally been conducted on the "extensive" rather than the "intensive" principle with the result that each soil sample has had perforce to be taken as representative of a fairly wide area. Even in the case of the more detailed surveys where each sample is made up of sub-samples taken at intervals of a few hundred yards there remains fairly extensive areas whose reaction (or composition) has to be assumed as that of some sample taken at a distance. Now the present study of a small area - 0.4 acre - of apparently uniform soil, which in more "extensive" work might well have been represented by one sample, showed that considerable variations occurred within distances of a few yards. The pH values of the samples bulked from cores taken at yard intervals from the sixteen 1/40 acre plots showed a range of from 4.62 to 5.59, while the lime requirements ranged from .248 to .300 per cent calcium carbonate. Further, such values as pH 4.90 and 5.59, (Plots 15 and 12) and lime requirements .248 and .290 (Plots 10 and 11) were obtained from contiguous plots. These figures are of the same order as is commonly found for and taken as representative of whole fields which may not even be adjacent. While it may not appear that the actual figures .248 and .290 per cent calcium carbonate show a very striking difference in themselves it has to be remembered that such determinations are frequently made not only for their academic interest but to supply information to the practical agriculturist on the treatment which his soil should receive. In terms of lime per acre the difference between these two figures represents fully half a ton.

It seems from the above considerations that a single determination for a whole field - even when the soil sample is made up of scattered cores - while not entirely valueless must be looked upon as a fairly wide approximation and when used as the basis of practical recommendations it should be recognised clearly that parts of the field may require half a ton per acre more than the test indicates.

Since pH values are much more easily determined that lime requirements it is unfortunate that no simple method has yet been devised of interpreting a pH reading into tons of lime per acre. Attempts to do this (6) (24)

(39) (49) have been made, though it is feared without much success. Nor is this altogether to be wondered at if an interpretation which would satisfy chemical accuracy is sought, for the pH value is a measure of the hydrogen-ion dissociation whereas lime requirements as understood at present are measures of base absorption under specific conditions, and there is not necessarily any fixed relationship.

Pure theory would lead one to expect this and in practice it has been proved for soils of different types but in the small area with which we are dealing one might expect that the inherent properties of the soil would differ so little from place to place that a parallelism would exist. Such however was not found to be the case. Thus for example Plots (12) (9) (3) and (14) showing lime requirements of .278, .278, .277, .276 had corresponding pH values of 5.59, 4.70, 5.23, 4.75 (Graph 7). The hope therefore of using pH values to indicate lime requirements even on soils of the same type seems more remote than ever.

While a considerable amount of work has been done of late years in the study of soil phenomena it has been in the main confined to the geo-chemical aspects. This is hardly surprising in view of the complexity of of soil problems and the difficulty of explaining satisfactorily all the observed facts. Even in the case of soil acidity, which is only one point among many, there is still vast scope for extension of knowledge, although the theories now current seem much more firmly based than formerly.

Attempts to link up the information which soil science in its more restricted sense has made available, with the responses of plants to the varying soil conditions have usually been of a more or less generalised nature. It is to be expected that species of different natural orders will show greater responsive differences than species within the same order, and the tendency is to work on material which will display distinctive differences. The ability to place say Beta maritima, Brassica napis and Dactylis glomerata in order of response to soil acidity or conversely to liming, while useful for some purposes is of little importance in the consideration of purely pasture problems where the vast majority of the plants belong to the one natural order.

Any competent observer will note in passing over an old pasture that irregularities in colonisation occur. A small patch consisting almost entirely of Lolium perenne and Cynosurus cristatus will be seen here, Agrostis there, Poa and Lolium yonder and so on. On the other hand if a pasture has been recently seeded and the seeds satisfactorily mixed and sown there is much greater uniformity. The naturally selective forces of soil conditions have not had time to be fully effective. It is certain that some soils are much more selectively discriminative than others and though data are not available with which to compare those presented here, one cannot but be impressed by the variations found from place to place over a small area which to the eye was outstandingly uniform for a pasture which had been down so long. For the eight principal species the following percentage ranges were found:-

L. perenne	1 - 18.
Dactylis glomerata	7 - 16.
Phleum pratense	0 - 10.
Festuca pratensis	2 - 12.
Cynosurus cristatus	6 - 16.
Poa trivialis	11 - 27.
Agrostis vulgaris	8 - 32.
Holcus lanatus	11 - 25.

While it is not claimed that soil acidity or the lime content, is likely to be wholly responsible for, or in certain cases even the dominant factor determining the nature of the community, it was thought probable that the soil reaction as indicated by either the pH or the lime requirement values might have some demonstrable influence in encouraging or depressing certain species.

Since from the nature of the experiment there were only sixteen percentage values for each species with the corresponding lime requirements and pH values it was not justifiable to apply the statistical device of expressing the degree of relationship by a co-efficient of correlation. A graphical method was therefore adopted which though less conclusive and definite mathematically, does nevertheless show where clear relationships do or do not exist.

No indisputable evidence of correlation between the percentage of any species and the lime requirement was found. There is just a hint however that there may be some connection between the percentages of Phleum pratense and Festuca pratensis and the lime requirement but the data are not sufficient to confirm it or otherwise.

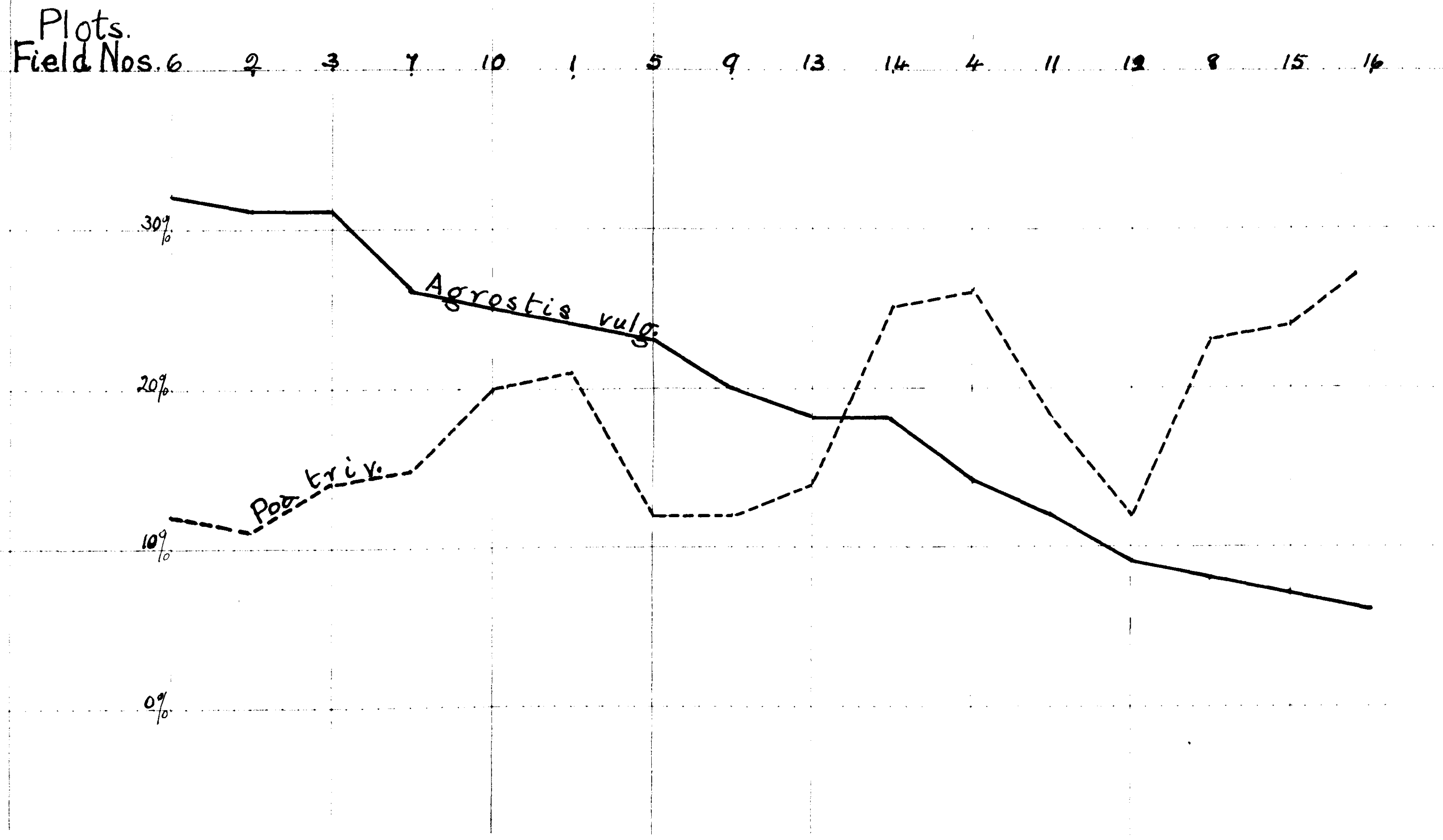
In so far as a positive result tends to be more spectacular than a negative one, the interest increases when a relationship is sought between the pH values and the percentages of the species. In the case of Lolium perenne, in spite of some small irregularities, we find a remarkably close agreement between the percentage which it contributes to the total herbage and the pH value of the soil (Graph 11). As the pH value falls so does the percentage of Lolium. In other words this grass is apparently much more sensitive to differences in the hydrogen-ion concentration of the soil than has hitherto been suspected - decreasing as the acidity rises. From a pH of 4.75 the amounts are quite inconsiderable. It is noteworthy also that with the exception of Agrostis, Lolium shows over the area a greater range (1%-18%) than any other species, which may be taken as further evidence of its sensitiveness to environmental conditions.

Dactylis glomerata and Cynosurus cristatus, on the other hand, while having a range of only half that of Lolium, show a decided trend in the other direction - increasing steadily with a rise in acidity. This is a particularly interesting finding since under other circumstances Dactylis and Cynosurus have been shown to benefit from liming. In these cases however competition from Lolium perenne was absent, due either to its not having been sown or to the acidity of the soil have been such as to eliminate it before liming took place. Thus there is really no incompatibility in finding an increased percentage of Dactylis and Cynosurus with greater acidity here, and finding these grasses to respond to liming where competitive conditions are different.

As to the other principal species no relationship between their amounts and the pH values could be traced. Poa trivialis, Agrostis vulgaris and Holcus lanatus all show considerable fluctuations from plot to plot, and apparently they are more influenced by factors beyond the scope of this enquiry than by such differences in acidity as these plots possess. Festuca pratensis and Phleum pratense (Graph 12) while not displaying any more correspondence with the acidity than the others show a marked parallelism with each other. Festuca is always present in slightly greater amount than Phelum but the respective percentages rise and fall together with great regularity indicating that the same factors influence these two in the same way though Phleum remains at a lower level.

It may be noted from Graphs (12) and (13) that Poa trivialis and Agrostis vulgaris show on many plots inverse fluctuations. To make this clearer Graph (14) shows the percentages of Agrostis in descending order, with the corresponding percentages of Poa. So far as these plots are concerned there obviously is a tendency

Graph 14. Percentages of Agrostis vulgaris in Descending Order, with Corresponding Percentages of Poa trivialis.



for Poa to increase as Agrostis decreases. Such a relationship apparently has not been previously noted but should it prove to be of regular occurrence it is probable that it depends on the readily available supply of some food element.

It is generally agreed that where land shows signs of acidity the yields will be increased by liming. But liming is regarded in large measure (and rightly so in many cases) as a necessary forerunner to the fullest returns being obtained from artificial fertilisers, without a very definite idea of what return might be forthcoming from lime per se. Moreover the amount of lime which may be economically applied - as distinct from that indicated by chemical tests - is not known. Even in times of financial stringency a farmer will strive to apply to his crops the orthodox amounts of artificial manures. There is however no orthodox amount of lime, and while 2 tons per acre (approximately .2% of weight of soil) is the amount commonly regarded as "a good average" dressing there is no compunction in reducing this very considerably in the cause of "economy".

On old pasture plots with an average lime requirement of .269% calcium carbonate, applications at the rates of .134%, .269% and .538% were made. All of these gave considerably increased yields over that from no treatment. As percentages of the mean yield they were 11.5, 13.9 and 24.4 respectively, with a Standard Error of 4.1%, showing that these increases are significant. A significant difference (10.5%) was also obtained between the .269% and .538% treatments but the difference was only 2.4% between the .134% and .269% rates, which is too small to be reliable.

It appears then from these results that if a lime requirement of from .2% to .3% is evinced, one may be quite confident of getting a considerably increased yield from old pasture by the application of anything over .1% of calcium carbonate. If however one is looking to lime alone for immediate results the choice lies between small dressings of about .1% and heavy dressings of about .5%.

SUMMARY and CONCLUSIONS

INTRODUCTION

The practice of using substances containing calcium as soil amelioratives is traced from early times to the present. It is shown that very large amounts of lime came to be applied but that following the introduction of artificial fertilisers the amounts were reduced and as a result of the War, liming ceased and is being resumed but slowly. Consequently the acidity of much agricultural land has increased.

The importance of pasture as a source of food is noted, and how a deficiency of lime reduces its value as a whole. Responses which the component species and strains make to variations in the lime status not being well known, investigations have been carried out to ascertain some of these.

POT EXPERIMENTS.

Details are given of three series of pot experiments wherein a number of grass species and strains were grown on acid soils to which varying amounts of calcium carbonate based on the Hardy lime requirements were added. The following conclusions are drawn -

(1) The official percentage germination of grass seeds is no guide to the number of seedlings which will appear.

(2) The number of surviving seedlings is influenced by the lime status of the soil. This number is usually increased by adding lime to acid soil.

Lolium perenne.

(3) The Ayrshire strain while developing 70 to 80 seedlings per 100 viable seeds on light acid soils may give over 90 when the soil receives its lime requirement, and almost every viable seed may develop a plant at four times the lime requirement.

(4) The Kent Indigenous strain develops 50 to 80 seedlings per 100 viable seeds on light acid soil: 80 to 90 at the lime requirement rate but numbers are not raised at four times the lime requirement rate. On clay loam, up to 80% of lime does not appreciably affect the numbers.

(5) Ayrshire and Kent Indigenous strains on light acid soil tend to tiller earlier and produce a greater number of tillers with increased lime up to four times the lime requirement.

(6) Indexes of growth show that the Ayrshire strain responds more than the Kent Indigenous to additions of

lime to acid sandy soil: on peaty soil the position is reversed.

(7) Ayrshire and Kent Indigenous strains produce more total growth and a greater number of tillers on neutral clay loam than on acid peaty soil receiving its lime requirement, but less growth and fewer tillers than on acid sandy soil similarly treated.

(8) Kent Indigenous on neutral clay loam benefits by increments of lime up to 10% by weight of the soil: at higher rates growth is arrested.

Dactylis glomerata.

(9) Danish, New Zealand and Welsh strains on untreated acid soils develop a small number of seedlings per 100 viable seeds - 46 to 66.

The range rises when the lime requirement is given, - 68 to 84.

At four times the lime requirement the number of Danish seedlings on sandy soil is less than at the lime requirement: on peaty soil it is greater. The number of New Zealand seedlings further increases on both soils. The number of Welsh seedlings increases on sandy but decreases on peaty soil.

The range on neutral clay loam is low - 54 to 66.

The averages for all soils and treatments are found to be - Danish 65.1, New Zealand 70.1, Welsh 70.7.

(10) Tillering commences earlier on sandy than on peaty soil.

(11) The higher the lime status (up to four times the lime requirement) the earlier does tillering commence. This leads to a greater number of tillers in autumn on peaty soil but not on sandy soil.

(12) Only a slight increase in the number of tillers is found when acid sandy soil receives its lime requirement.

On acid peaty soil, tillering does not take place (during the first year), but is induced when the lime requirement is given.

(13) The New Zealand and Welsh strains develop a greater number of tillers on neutral clay loam than on peaty soil receiving its lime requirement and approximately the same number as on sandy soil. The Danish strain develops a smaller number on clay loam than on the other soils.

(14) The Welsh strain on peaty soil receiving four times its lime requirement gives the greatest number of tillers, of all the strains, soils and treatments tested.

(15) Indexes of growth show that on sandy soil the addition of the lime requirement has no appreciable effect on either the Danish or New Zealand strains but increases the Welsh. Four times the lime requirement

depresses the Danish, increases the New Zealand and has no further effect on the Welsh.

On peaty soil, the lime requirement causes a marked increase in each strain. Four times the lime requirement gives a further increase in each.

(16) The averages of indexes of growth on sandy soil show that, over all, the New Zealand gives the greatest growth, that of the Welsh is only slightly less while the Danish gives least. On peaty soil the averages of New Zealand and Welsh strains are equal and slightly greater than of Danish.

(17) The index of growth for the Danish strain on neutral clay loam is very low, for the New Zealand and Welsh it is almost as high as on sandy soil at the four lime requirement treatment though not so high as on the peaty soil at this treatment.

<u>Phleum pratense</u>.

(18) The number of seedlings, as percentages of viable seeds, produced by Scotch and Gloria strains is high, by the Welsh strain it is low. The averages for all soils and treatments are found to be, Gloria 88.9, Scotch 84.5, Welsh 61.2.

(19) Scotch, Welsh and Gloria strains show a very

small increase in numbers of seedlings when acid sandy soil is treated at either the lime requirement rate, or four times that rate. On peaty soil the increase is much greater and is continued with the higher rate of treatment.

(20) The Gloria strain grows more rapidly and the Welsh more slowly than the Scotch.

(21) On acid sandy and peaty soils the additions of the lime requirement and four times the lime requirement promote additional growth of all three strains.

(22) On untreated acid peaty soil all the seedlings of Gloria and many of the Scotch and Welsh strains die.

(23) The date at which inflorescences are produced is influenced on sandy soil by the lime status. On all strains considered, they appear first at the four lime requirement rate and four days later at the lime requirement rate. The Scotch and Gloria flower at approximately the same dates, with the Welsh seven days later.

The Scotch is the only strain producing inflorescences (in the seedling year) on untreated acid sandy soil and neutral clay loam. These appear sixteen days later than on sandy soil receiving the lime requirement.

(24) The Scotch strain develops a greater number of tillers on acid sandy soil when the lime requirement is

given; at four times that amount the number is not appreciably increased. The Welsh strain gives progressively greater numbers at each treatment while the Gloria is little influenced.

On acid peaty soil the Scotch and the Welsh produce no tillers in the absence of lime, a few where the requirement is given but no substantial increase at four times the requirement. Gloria, on this soil either with or without lime, produces no tillers.

(25) The Welsh strain, while having a greater inherent tendency to tiller than the others, is more influenced by lime and can respond to larger amounts.

(26) Indexes of growth show that by early autumn, on sandy soil untreated and treated at the lime requirement rate, the Scotch strain has made most growth. The increase due to treatment is also greatest for the Scotch. The differences in indexes of growth between treatment and no treatment are, Scotch .84, Welsh .64, Gloria .02. At four times the lime requirement the total growth of the Scotch was the same as at no treatment. The Welsh and Gloria made a further slight increase.

On peaty soil the Scotch gives the greatest growth at all treatments and Gloria the least. Growth by all strains is greater on neutral clay loam than on peaty soil irrespecitve of the treatment of the latter. It is greatest for the Welsh and least for the Gloria strain, which is very weak on the clay loam.

Alopecurus pratensis.

(27) The number of seedlings as percentages of viable seeds sown is always small for this species: it never exceeds 63.0 and may be as low as 10.9. The number is not appreciably increased by adding lime to acid sandy soil, but on peaty soil considerable increases are obtained both by adding the lime requirement and four times the lime requirement.

On neutral clay loam the number is higher than on peaty soil at any treatment but lower than on sandy soil at any treatment.

(28) On sandy soil, added lime gives greater tillering and greater leaf length; on peaty soil it prevents some of the plants, though not all, from dying, but does not induce tillering.

Poa trivialis.

(29) The number of seedlings as percentages of viable seeds ranges only from 76.9 on untreated acid sandy soil to 80.2 at four times the lime requirement: while it rises from 4.4 on untreated peaty soil to 61.5 at the lime require-

ment but does not rise further at four times the requirement. On neutral clay loam it is 72.5.

(30) More tillers are produced on sandy soil receiving the lime requirement than when untreated. Four times the lime requirement increases both number of tillers and leaf length.

On untreated acid peaty soil all the plants die. Some survive and tillering takes place when the lime requirement is given and tillering is increased with four times that amount.

(31) Growth is greatest on sandy soil, least on peaty soil and intermediate on clay loam.

Cynosurus cristatus.

(32) On acid soil, of high organic matter content, growth is hastened in the early stages by lime at three times the requirement rate.

(33) The addition of lime to acid soil induces growth earlier in spring.

Agrostis vulgaris.

(34) On acid soil growth is more rapid in the seedling stage when three times the lime requirement is given.

Festuca ovina

(35) Liming, at rates higher than the lime require-

ment, retards seedling growth on acid soil of high organic matter content.

(36) At three times the lime requirement rate, plants survive the winter more successfully and commence growth earlier in spring than where the soil is untreated.

PLOT EXPERIMENT

To test the effect of increments of calcium carbonate on a loam showing a low lime requirement (Hardy), eight species were grown on small plots. Observations were made throughout two years. Thereafter chemical determinations of their calcium and nitrogen contents were made. The conclusions are -

(37) Grasses only show faint responses to increments of calcium carbonate up to three times the lime requirement on soil where the reqmirement is small.

(38) On such soil and under such treatments the calcium and nitrogen contents show no regular trend.

(39) Phleum pratense on soils receiving two or three times the lime requirement shows less winter burn, greater succulence, greater leaf development, and higher percentages of calcium and nitrogen than on soils untreated or receiving the lime requirement.

(40) Poa trivialis when two or three times the lime

requirement is given commences growth earlier in spring than when the lime requirement or no treatment is given. This species develops more tillers with added lime.

(41) Festuca ovina shows less winter burn with additions of lime (see 36) but otherwise is not visibly affected.

(42) Only Festuca ovina, Cynosurus cristatus and Agrostis vulgaris show the highest calcium content at the highest rate of liming.

PASTURE EXPERIMENT.

Results of field experiments extending over four years are presented. Pasture plots on acid soil at three centres received lime at two rates - a standard two-ton rate and the lime requirement (Hutchinson and McLennan) rate. pH and lime requirement (H. & McL. and Hardy) values were found for the plots at the commencement of the experiment and after two and four years. At the conclusion, botanical analyses were made. The findings are -

(43) The percentage of Agrostis is considerably reduced by both treatments. Sometimes the lime requirement rate is the more effective and sometimes the standard and the lime requirement rates are equally effective.

(44) The percentage of Holcus is only slightly reduced by either treatment.

(45) The percentage of Anthoxanthum is somteimes reduced equally by both treatments at others the standard rate is the more effective.

(46) When Festuca ovina is originally present in appreciable amount, the diminished aggression from Agrostis and Anthoxanthum through liming, allows it to increase. The increase is greater at the lime requirement than at the standard rate.

(47) Poa is found to behave in the same way as Festuca ovina.

(48) The percentage of Cynosurus cristatus is increased by liming. When present originally in appreciable amount its percentage increases proportionally as the sum of the percentages of Agrostis, Anthoxanthum and Holcus decreases.

(49) Dactylis glomerata shows a slight tendency to increase with additions of lime.

(50) On strongly acid soils the lime requirement rate generally effects greater changes in the composition of the herbage than the standard rate of liming.

(51) The rate of liming which effects the greatest fall in the lime requirement (H. & McL) also effects the

greatest change in botanical composition.

(52) On testing the acid soils receiving the lime requirement (H. & McL) and the standard rates of liming, after four years it is found that where one rate has induced a greater fall in the Hutchinson and McLennan lime requirement than the other, then that rate has induced a smaller fall in the Hardy lime requirement than the other.

(53) On some acid soils treatment at the lime requirement rate (H. & McL) almost eliminates the requirement; on others it reduces the requirement by only a third.

FIELD SURVEY

An area of approximately three square miles was surveyed botanically in an attempt to relate the percentages of the principal species with available data on the soil reactions. Botanical analyses, soil data and graphs combining these are given. The deductions are -

(54) The percentages of the commoner herbage species cannot be correlated with lime requirements taken as representative of several acres.

(55) The percentages of the commoner herbage species show either very faint correlation or none with pH values

taken as representative of several acres.

LATIN SQUARE EXPERIMENT

Statistical tests of significance were applied to yields obtained from old pasture. Plots were arranged in the form of a 4 x 4 "Latin square", four (including control) rates of liming being given. In this experiment soil and botanical readings were made in much detail. Graphs show where these were related. The conclusions are -

(56) A small area (0.4 acres) of apparently uniform soil shows ranges of pH values from 4.62 to 5.59 and of lime requirements (Hardy) from 0.248 to 0.300 per cent. calcium carbonate, therefore single values representing several acres are unsatisfactory.

(57) Even in this small area correlation is not found between the lime requirement and pH values.

(58) The percentage composition of pasture varies considerably from point to point within a small area even when the herbage is apparently uniform.

(59) No clear evidence of correlation between the percentage of any species and the lime requirement is found.

(60) Determinations being made at sufficiently small

intervals there is a close agreement between the percentages of Lolium perenne and the pH values, - as the acidity rises the percentage of Lolium falls.

(61) As the percentage of Lolium perenne rises, the percentages of Cynosurus cristatus and Dactylis glomerata fall.

(62) The percentages of Poa trivialis, Agrostis vulgaris, Holcus lanatus, Festuca pratensis and Phleum pratense, under the conditions of this experiment are not correlated with the pH values.

(63) The percentage of Poa tends to increase as that of Agrostis decreases.

(64) The percentages of Festuca pratensis and Phleum pratense tend to rise and fall together.

(65) Old pasture plots of average lime requirement 0.269 per cent. calcium carbonate having received half the lime requirement, the lime requirement and twice the lime requirement all show considerable increases in yield over untreated plots. As percentages of the mean yield these are 11.5, 13.9 and 24.4 respectively, with a standard error of 4.1

Increments from the lime requirement rate and twice the lime requirement rate over half the lime requirement rate are thus 2.4 and 12.9 per cent. respectively: and the increment from twice the lime requirement rate over the lime requirement rate is 10.5 per cent.

The rates therefore which give the greatest yields for the amount of lime applied are half the lime requirement and twice the lime requirement.

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APPENDIX A.

THE "POINT QUADRAT" METHOD of PASTURE ANALYSIS

Pasture analyses have always presented difficulties. Methods whereby actual turfs are lifted and the plants carefully separated are so laborious as to rule them out for extensive work. An advance was made by Armstrong (52) in the introduction of the "Percentage Area" method. In this a mesh 12 ins. by 12 ins. subdivided into 144 or 100 equal squares is used. The area occupied by each species is estimated by eye and calculated as a percentage of the whole. The objections to this method are its slowness and the amount of reliance which has to be placed on the personal element.

As Davies (53) points out, the Point Quadrat method is a modification of the Percentage Area method and has been employed recently by Levy (54) in New Zealand. The apparatus consists essentially of a frame carrying ten pins set two inches apart in a row. The frame with the pins pointing downwards is placed over the herbage so that the pin points touch it. The species touched by each point is noted and the process is repeated according to the number of readings to be made. The percentage of each species is then calculated from the number of times out of the possible that it has been recorded.

The apparatus may be regarded as a linear mesh but has the advantage of each point being clearly defined so that there is the possibility of greater accuracy. Only ability to recognise the species is required of the worker and reliance on judgment is largely eliminated. This permits of readings being taken much more rapidly than if the square mesh were used.

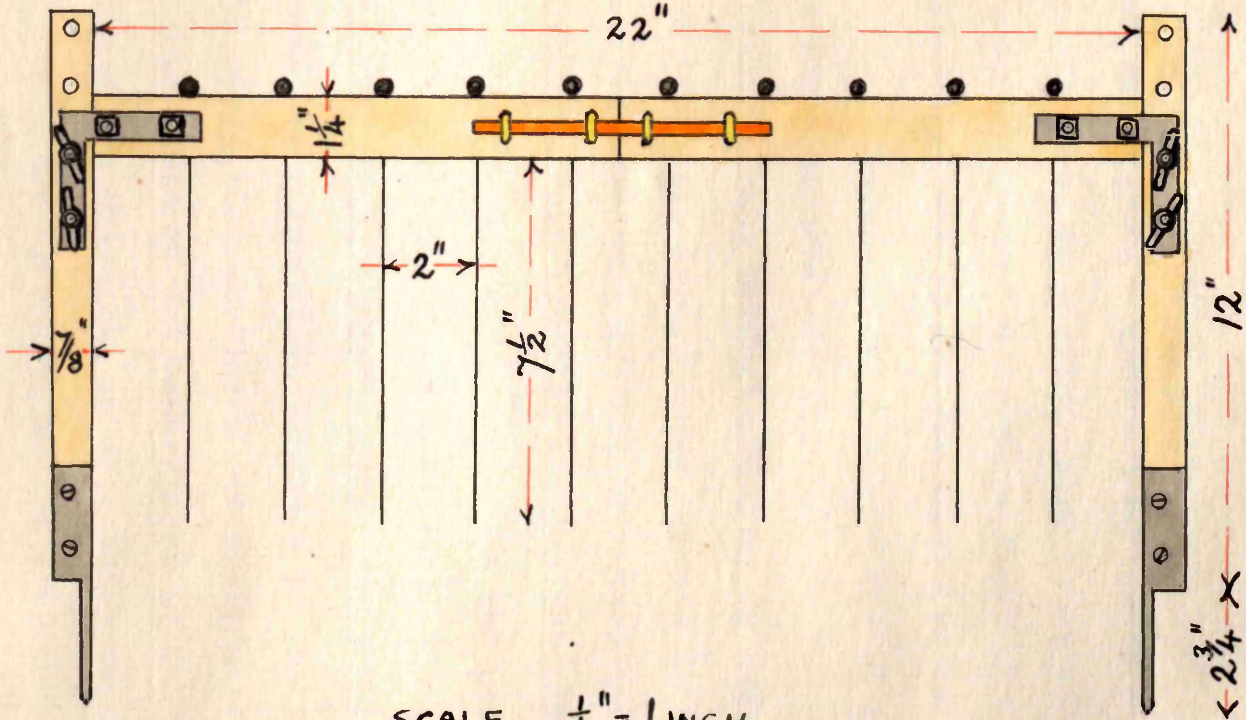
In the few cases where the Point Quadrat method has been employed previously, the results have been entirely satisfactory and under critical examination (53) have approximated closely to those from the Percentage Area method, and that of cutting and weighing the component species.

Prior to the investigations, recorded earlier, suitable apparatus was not available so had to be constructed. So far as could be gathered, Levy's apparatus consisted of a rigid metal frame into which the pins were fitted. This seemed rather cumbrous so several modifications were made.

DETAILS of APPARATUS

Horizontal wooden bar 22" x $1\frac{1}{4}$" x $\frac{3}{4}$", drilled

POINT QUADRAT APPARATUS



SCALE ¼" = 1 INCH

at 2" intervals to take pins. Bar hinged at centre. Four metal loops at opposite side of bar from hinge, with wooden bolt.

Two right angled metal straps, arm lengths 3", width $\frac{5}{8}$". One arm of each strap bolted to ends of horizontal bar, other arm projecting downwards.

Two wooden uprights 12" x $\frac{7}{8}$" x $\frac{7}{8}$" drilled at four $1\frac{3}{8}$" intervals from top, to take $\frac{1}{4}$" bolts and thumb screws.

Two cylindrical metal spikes $5\frac{1}{8}$" x $\frac{3}{16}$", each projecting $2\frac{3}{4}$" from respective feet of uprights.

Ten pins, $8\frac{3}{4}$" long.

To assemble the apparatus the wooden bolt is pushed through the metal loops thus keeping the horizontal bar rigid. The uprights are then attached to the horizontal bar by bolting them to the downward projecting arms of the angled straps and tightening the thumb screws - two bolts and screws to each upright. The pins are next forced through the holes in the horizontal bar and the apparatus is ready for use. (Photograph 24.) Since the uprights are drilled at four places and carry two bolts they may be fixed at any one of three positions, that is, the horizontal bar may be raised or lowered, as required, depending on the average height of the herbage.

Photograph 24.

Point Quadrat apparatus ready for use.

Photograph 25.

Point Quadrat apparatus dismantled and packed.

To dismantle, the pins are withdrawn, the uprights detached, the wooden bolt withdrawn from two of the loops and the horizontal folded. The component parts may then be packed together to occupy a comparatively small space. (Photograph 25.)

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APPENDIX B.

LATIN SQUARE EXPERIMENT

COMPLETE SOIL DATA

DATA from PRELIMINARY SOIL SAMPLES.

Plot	SOIL		SUB-SOIL	
	pH	L.R.	pH	L.R.
1.	4.90	0.202	5.02	0.102
2.	4.50	0.160	5.40	0.097
3.	4.43	0.226	4.48	0.165
4.	5.11	0.202	4.72	0.151
5.	4.46	0.222	4.53	0.127
6.	5.02	0.216	4.81	0.127
7.	4.63	0.184	5.14	0.157
8.	4.50	0.259	4.50	0.168
9.	5.07	0.205	4.52	0.136
10.	4.97	0.217	4.70	0.112
11.	4.77	0.228	5.05	0.142
12.	4.29	0.262	4.90	0.217
13.	4.43	0.241	4.60	0.138
14.	4.64	0.258	4.52	0.157
15.	4.70	0.249	4.60	0.232
16.	4.36	0.249	4.39	0.228

DATA from "BULK" SOIL SAMPLES

Plot	SOIL		SUB-SOIL	
	pH	L.R.	pH	L.R.
1.	4.81	0.274	4.90	0.153
2.	4.91	0.249	5.63	0.153
3.	5.23	0.277	5.14	0.152
4.	5.24	0.270	5.16	0.195
5.	5.02	0.252	5.00	0.150
6.	4.85	0.255	5.56	0.150
7.	4.95	0.255	5.56	0.150
8.	4.93	0.255	5.37	0.180
9.	4.70	0.287	5.07	0.149
10.	4.95	0.248	4.79	0.150
11.	4.95	0.290	5.65	0.213
12.	5.59	0.278	5.43	0.219
13.	4.62	0.263	5.07	0.192
14.	4.75	0.276	5.21	0.180
15.	4.90	0.285	5.47	0.210
16.	5.31	0.300	5.47	0.225

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1000 Feet 500 0 1000 2000 3000 4000 5000 5280 Feet
1 Furlong 0 ¼ ½ ¾ 1 Mile

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The Altitudes are given in Feet above the assumed Mean Level of the Sea at Liverpool, which is 0·650 of a Foot below the general Mean Level of the Sea.
Altitudes indicated thus B.M. 54·7 refer to Bench Marks on Buildings, Walls, &c. those marked thus · preceded or followed by the height, to surface levels.

SHEET XXXV

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S.W.	S.E.