LIME INVESTIGATIONS ON FOUR CANTERBURY SOIL TYPES

The Correlation of Laboratory Determined Lime Requirements with Field Responses and the Relation of Differential Reactions Obtained to the buffer capacity of the Soils as expressed by their Organic and Inorganic Colloidal Content.

THESIS

Presented for M.Agr. Sc. and Honours.

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FOREWORD

The application of lime to soils, in quantities based upon chemical methods of determining lime requirements, is but rarely practised by the New Zealand farmer. He usually bases his decisions as to whether or not a field requires lime, on his own experience, coupled with the traditional knowledge that has been accumulating on the problem since the earliest days of farming. Moreover, he is dependent upon qualitative factors when he attempts to estimate the quantity of lime which should be applied. Such factors as the abundance of weeds like sorrel or spurrey; the poor unthrifty growth of clovers; the difficulty of developing a fine tilth and the presence of undesirable physical properties of the soil, have long been associated with soils responsive to liming, but they are of doubtful value when used as a basis for determining quantitative applications of lime.

The advance from the qualitative stage of liming to the quantitative is, however, very difficult, and necessitates the use of chemical methods to determine the exact amount of lime which should be applied to the soil to bring about a definite reduction in acidity. This definite amount is termed the Lime Requirement of the soil. Up to the present time, no New Zealand investigator, with the possible exception of J. K. Dixon, has succeeded in satisfactorily correlating chemical determinations of lime requirement made under laboratory conditions with field responses. Reasons for failure have been many and varied, but not the least important factor has been the lack of a suitable method of laboratory analysis. The recent development of an electrometric titration technique by Christensen and Jensen ( ) for measuring lime requirement is regarded as being sufficiently sound and practical to justify an investigation of

its application to New Zealand soils.

It is the aim of this investigation to determine the lime requirement of samples from four Canterbury soil types, using the method mentioned above as modified by G. Mitchell ( ) and to correlate the results obtained, with field responses, as indicated by pH changes, induced by dressings of known quantities of commercial ground limestone.* The results thus obtained should provide a basis from which it will be possible to give definite recommendations as regards liming practices on the four soil types selected, and to predict the changes in acidity which will take place as a result of applying different quantities of limestone.

Differential responses given by the various soil types, and in some cases by soils on a single type, are noted, and the principles underlying them evolved and explained as far as possible in the time available.

* Throughout this paper the words lime and limestone are synonyms, meaning commercial ground linestome.

PART I

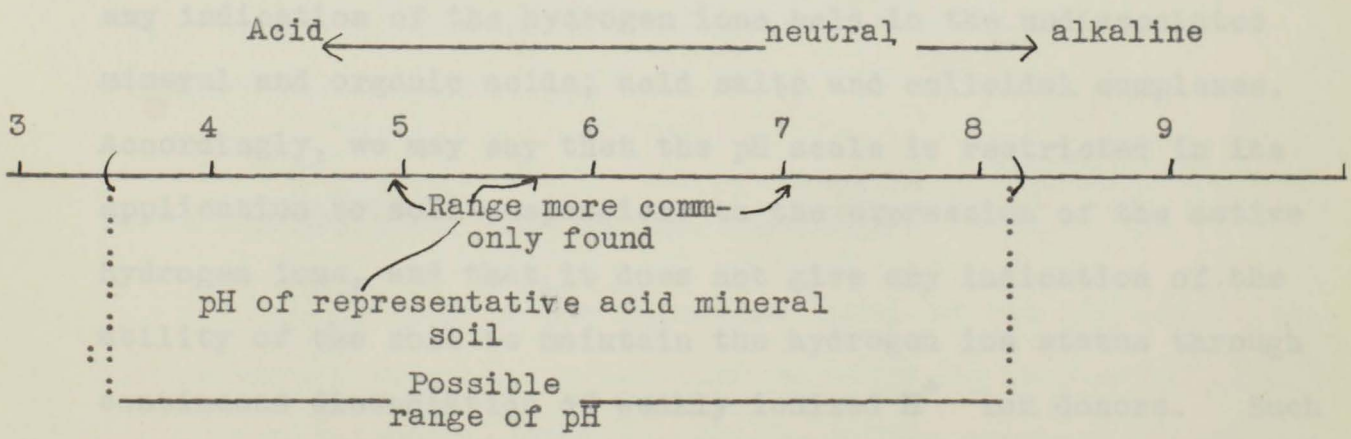
CHAPTER I - INTRODUCTION

A. THE CONCEPTION OF SOIL ACIDITY.

A solution is considered to be neutral when it contains equal quantities of hydrogen $[H^+]$ and hydroxyl $[OH^-]$ ions. Such a state is seldom found, except in very pure water, other systems containing either a preponderance of hydrogen or acid ions, or a superior number of hydroxyl or alkaline ions. Acidity thus obtains when H^+ ions preponderate. Since it would be relatively inconvenient to express the absolute number of hydrogen ions on a numerical basis, it has become a regular practice to make use of the pH scale first introduced by Sorensen.* This scale ranges from pH0, which represents the extreme acid limit, to pH 14, the extreme alkaline limit. Neutrality is expressed by pH 7.

This scale has been successfully used to indicate the presence or absence of acidity in soils, and the position is ingeniously expressed by Lyon and Buckman ( ), whose table is reproduced below.

TABLE I



* The pH value of a solution is related to the number of H^+ ions present, since it represents the common logarithm of the reciprocal of the hydrogen ion concentration expressed in normality or pH = $\log \frac{1}{[H^+]}$

The relation of the pH scale to the practical expression of soil acidity has also been summarized by Lyon and Buckman ( ), see Table II.

TABLE II

Soil Condition	pH value	Soil Condition,	pH Value
Very alkaline,	above 7·5	Moderately acid,	5·5 - 6·0
Alkaline,	7·0 -7 ·5	Highly to mod. acid,	5·0 - 5·5
Neutral,	7·0	Highly acid,	4·5 - 5·0
Slightly acid,	6·0 - 7·0	Very highly acid,	Below 4·5

There are other tables expressing similar results, and additional discussion on the relation of practical terminology to the readings on the pH scale will be deferred until the section on discussion of results, (p).

There are several disadvantages attendant on the use of the pH scale as a measure of soil acidity, and a knowledge of these peculiarities is essential for the proper interpretation of soil acidity measurements.

The determination of the pH of soils is usually done in an aqueous suspension. However, this procedure only gives a measure of the "active" hydrogen ions and does not give any indication of the hydrogen ions held in the undissociated mineral and organic acids, acid salts and colloidal complexes. Accordingly, we may say that the pH scale is restricted in its application to soil suspensions to the expression of the active hydrogen ions, and that it does not give any indication of the ability of the soil to maintain the hydrogen ion status through continuous dissociation of weakly ionized H^+ ion donors. Such continuous dissociation is chiefly a property of the clay and humus complexes, and the process is termed the buffering action of the soil. In this investigation, the type of lime response

is correlated with the buffering agents as evidenced by the determinations of colloid content and of loss of ignition.

Other peculiarities which must be considered when using the pH scale have been summarized by Lyon and Buckman ( ) as follows: -

" (1) As the hydrogen ion concentration increases, the pH value decreases and vice versa.

(2) The change in hydrogen ion concentration is geometric and not arithmetic, since there are 9 acid units between pH 7 and 6, 90 between pH 6 and 5, 900 between 5 and 4, and so on.

(3) Alkalinity is expressed in terms of hydrogen ion concentration, a pH greater than 7 indicating an alkaline reaction.

(4) The system conflicts with our mental habits, since our thinking is along the lines of arithmetic rather than geometric progression. "

The use of the pH scale persists, however, because of its linear relation to the voltage readings of the potentiometer. It affords a single figure indicative of the hydrogen ion concentration.

The conception of H^+ ion concentration is the scientific outlook on the expression of soil acidity. The farmer, on the other hand, adopts a different and somewhat indefinite scale of acidity. In place of pH units, he recognizes degrees of sourness, and his potentiometer is his own experience, plus the traditional knowledge the farming community has for generations been accumulating.

B. THE DEVELOPMENT OF ACIDITY IN SOILS.

Soil is the outermost layer of the earth's crust, and is formed from the parent rock material by weathering agents acting in conjunction with the decomposition products of added organic residues. From a consideration of this mode of origin, it can be seen that, in cases where soils have been recently derived from the parent rock material, the acidic or basic nature

of the soil will depend upon these characteristics in the parent material. Similarly, geologically old soils are little affected in areas where weathering agents are very much reduced in intensity.* Soils developed under these two sets of conditions are termed "pedologically young" soils.

Changes in the character of soils with regard to their base status are brought about by the action of weathering agencies, and the magnitude of the change depends on the intensity of the weathering processes, and the length of time over which they have been operating. Soils which have been subjected to extensive weathering over a long period are termed "pedologically old" soils.

(1) Soils Dominated by Parent Material, or "Pedologically Young" Soils.

The nature of the parent material must, of course, play a considerable part in determining the rate of profile development. Thus, in humid regions, soils derived from strongly basic rocks such as limestone, dolomite and the calcureous sandstones or papas, tend to develop acidity more slowly than do those derived from rocks with a low base content, such as granite and rhyolite. Soils dominated by the character of the parent material are found under two sets of conditions : firstly when soils are very young geologically, and secondly when weathering is reduced in intensity.

(a) Skeletal Soils, or Soils of Recent Origin.

Under these conditions, the nature of the parent material is the dominating factor in determining the soil type, for weathering agents have not had time to induce marked changes. Excellent New Zealand examples of this class of soils are the pumice soils of the Central North Island, the parent material of which originated from ash showers, the last of which was in 1886. The soils are classified according to their parent ash shower into

* By intensity of weathering, it is meant the extent to which the process goes on in a given time.

Taupo series; Tarawera series, etc. Grange ( ). The sheaf deficiency disease known as "dopiness" or "Mairoa disease" is associated by Grange ( ) with a definite soil type derived from Mairoa ash. According to Dixon ( ) this ash develops into soil which is definitely lime deficient, due to the low lime content of the parent material.

(b) Where Weathering is Reduced in Intensity.

Weathering is reduced to a minimum where the addition of water by precipitation exactly equals the loss of water by evaporation. Under these conditions, there is no drainage of gravitational water through the soil, and consequently no loss of soluble bases by leaching. Neither do soluble salts accumulate in the surface layer of the soil, due to the upward movement of the soil solution, and the evaporation of the water from the surface.

A condition of climatically induced equilibrium results, and the soil maintains its original composition over long periods. Such a condition exists in Central Otago, where the soil has retained the original composition of its rich parent micu-schists, and, although geologically old, is pedologically young due to a scanty rainfall.

(2) Soils Changed by Weathering Processes, or "Pedologically Old" Soils.

The intensity of the weathering processes is chiefly a function of climate, and changes in soils induced by climatic factors have been extensively used as a basis of soil classification, (Glinka). The nature of the organic residues added to the soil also influences the intensity of the weathering processes, and may accelerate or modify the changes induced by various types of climate. It is proposed to discuss firstly the effects of climate, and secondly, the modifications of the climatic effects induced by various plant associations.

(a) Influence of Climate.

Soil acidity is a state in which acid or hydrogen ions predominate in the soil solution. To induce this condition in soils derived from parent material which is, for the most part, neutral or alkaline, some agent producing hydrogen ions must be present, together with a process for distributing them throughout the soil, and removing the equivalent bases liberated. The agent distributing the hydrogen ions and removing the liberated bases is the percolating water. In humid regions where precipitation evaporation, this percolating water is saturated with carbon dioxide derived from the atmosphere, and liberated during the decomposition or organic matter. The percolating water also contains organic acids derived from the break down of organic matter by cellulose destroying bacteria and fungi. The highly mobile hydrogen ions displace the less firmly held cations from the colloidal clay and humus complexes. These displaced cations combine with the bicarbonate ions in the soil solution to give soluble salts, which are leached out in the drainage waters. Hydrogen comes to dominate more and more the colloid complexes, and the change is reflected in steadily increasing soil acidity.

The rate at which this cationic interchange takes place, has been shown by Russell ( ) in the Rothamsted lysimeter experiments to be related to the mean annual rainfall, and mean annual temperature. There are other factors which may modify the rate of change such as vegetative cover, seasonal distribution of the rainfall and texture of the soil, but, in general, acid soils are developed in high rainfall districts. The leaching process develops along distinctly different lines under moderate temperatures, and under high temperatures.

Under moderate to low temperatures, a distinct type of acid soil known as the podsol develops. Such soils are characterized by very well marked horizons in the soil profile. The higher the rainfall the more marked are the horizons, and the

greater is the development of soil acidity.

Under high temperatures, a different type of weathering occurs, and different processes follow leaching of the soluble salts from the surface layer. The acidity developed, however, just as with podsols, depends on the amount of percolating water.

(b) Modifying Influence of Vegetation.

Vegetation modifies the action of climate by the provision of a dynamic circulation of basic material. The bases are absorbed from the lower layers of the profile by the roots, and are returned to the surface by way of the fallen leaves, twigs and bark. Accordingly, the type of vegetation and, in particular, the base content of its litter, greatly influences the rate at which acidity is developed in the upper layers of the soil profile. This is well illustrated by a comparison of certain plant associations.

Coniferous forests and certain heath associations produce litters which have a very low base content, and as a result, the waters percolating through the soil carry an excess of hydrogen ions, derived from the organic acids and carbonic acid produced so abundantly. These hydrogen ions tend to replace the exchangeable bases in the colloid complexes, and the soil becomes steadily more acid and unsaturated. On the other hand, deciduous forest containing associations of dominant oak, elm and ash, produces a litter containing a high percentage of bases as compared with coniferous forest. If the amount of bases so added to the percolating waters is sufficient to offset the losses displaced by the H^+ ions, then the soil remains in equilibrium. This is the case in the Brown Forest soils, which are thus maintained almost neutral by a vegetational force under podsol climatic conditions. Should the amount of bases replaced in the colloid complexes be less than the amount displaced, then the acidity of the soil steadily increases.

The action of the various plant associations on the development of acidity in New Zealand soils has not been studied to any great extent, but clear evidence, indicating that acidity is rapidly developed under the kauri and most of the other evergreen trees is presented in field observations at North Auckland, (Taylor and Sutherland), and in Westland, (Burns,). Other associations may also produce litters with low base contents, and as an example, no better illustration could be given than that of manuka scrub. It would be reasonable to say that with but minor exceptions (as puriri, taraire, etc.,) all New Zealand forests tend to accelerate the development of soil acidity, rather than retard it.*

The influence of vegetation on the development of soil acidity is therefore rather complex. However, it reaches its maximum intensity under virgin forest conditions, and the associations of the ordinary pasture grasses and clovers exert only a small influence on the rate of development of soil acidity.

C. THE RELATIONSHIP OF SOIL ACIDITY TO PLANT GROWTH.

Ecological classifications of plants have been based on various factors, including soil acidity. Both native plants and common crop plants have been classified, and various ranges of hydrogen ion concentration, over which common plants make optimum, growth have been put forward. (Arrhenius, M rley Davis,). Most plants thrive best on a slightly acid soil, though some,like members of the Erica family, and oats, prefer an acid soil. On highly acid soils, however, the conditions

* Further evidence is furnished in a report on Forest litters, (N.H.Taylor and J.K.Dixon, Report on Soil Survey, 1937-38. p.12).

"Analyses of the forest-floor samples, although incomplete, show the litter of dicotylous to contain more lime and potash than does the litter of the kauri. The alkalinity of the litter ash, (i.e. the excess of basic over acidic constituents), agree with the field evidence in placing the trees in the following order : puriri, taraire, rimu, kauri. The puriri produces the most fertile soils from a given parent material, and the kauri the least fertile."

induce a typical flora of lower fertility plants, New Zealand examples of which are: -

Sorrel (Rumex acetosa and R. acetosella), Spurrey (Spergula arvensis) all Agrostis species (Browntop,redtop, and creeping bent), Yorkshire and Creeping Fog (Holcus lunatus and H.mollis), sweet vernal (Anthoxanthum odoratum), and moss.

Lack of lime causes certain pathological conditions in roots and leaves of plants, but the chief effect appears to be to accentuate any other deficiency which might be present. Many explanations have been advanced to explain acid injury and the dominance of the typical acid soil plant associations. They are discussed under two headings; firstly soil acidity as a direct factor, and secondly indirect factors associated with acid soils.

(1) As a Direct Factor.

It was believed by the early investigators that plants growing on acid soils were directly injured by the acids present. This view has been upheld by C. Olsen ( ), who investigated the problem closely, and considers that the injury is due to the hydrogen ion concentration itself. Against this is held the fact that plants will grow in water culture solutions at far higher hydrogen ion concentrations than in soils.

The view that plants fail to grow on acid soils because of the direct absence of calcium,is held by a number of investigators. Available calcium falls sharply on acid soils,* and many plants, expecially members of the Leguminosae require calcium in large amounts.

The following are some of the adaptations which it

* MacIntire (

The quantity of calcium available in average soil is in the ration of

pH 4	=	1	pH 7	=	14
pH 5	=	4	pH 8	=	22.
pH 6	=	8			

has been suggested enable plants to survive under conditions of low available calcium supply. Priestly ( ) suggests that plants characteristic of sour badly aerated peats produce large quantities of fat just behind the growing point, and calcium would tend to form insoluble soap and choke the tissues. Clements and Weaver ( ) consider that plants of low calcium content making slow growth are able to survive by virtue of extensive root systems. Timothy, linseed, rye and red-top are given as examples. That lack of calcium is a limiting factor is supported by the fact that calcifuges can endure on acid soils provided calcium is present in certain quantities.

(2) Other Factors associated with Acid Soils which may influence Plant Growth

Other theories have been advanced from time to time to account for the selective action of soil acidity. At a concentration of hydrogen ions represented by a pH of about 4·7, compounds of iron and aluminium become soluble. Aluminium, which is toxic to plants above a definite concentration, is therefore considered to be the major factor limiting plant growth, by some United States, Hawaian, and Indian stations. Also the greater amounts of soluble iron and aluminium present in acid soils fix more phosphate in an insoluble form which is unavailable to the plant.

Under acid conditions, the activity of the soil micro flora and fauna is reduced, so that organic residues added to the soil tend to accumulate on the surface as acid humus, rather than be made available to the plant as simple decomposition products. This is especially the case with nitrogen,as nitrifying organisms are especially sensitive to acidity and do not function below pH 5·5 (MacIntire). The accumulations of undecomposed humus have been supposed by some to contain organic toxins which reduce plant growth.

The clay and humus colloid complexes of acid soils

are dominated by hydrogen, and have characteristically poor physical conditions. Water-relationship are poor for the soils, are water-logged during wet weather, and suffer from a lack of aeration; and are parched during dry seasons.

Soil acid is one factor in a complex involving low pH, lack of active calcium, high concentration of soluble iron and aluminium, possibly organic toxins, poor physical conditions of the soil, and a low availability of bitrogen and phosphate. It seems that not any one of these factors operates alone, but that the action of soil acidity on plant growth is a combination of them all in different proportions under different circumstances.

D. REDUCTION OF ACIDITY ON HIGHLY ACID SOILS.

Since soils in which calcium is the dominant cation in the colloid complexes possess the most desirable physical and chemical properties, it has become the common practice to apply as ameliorants to acid soils compounds of calcium. The most frequently used salts are the carbonates, (or its closely related oxide or hydroxide), the silicate, and the sulphate. Strictly speaking, the last mentioned - which does not influence the soil acidity - should be considered only as a soil amendment.

(1) Calcium carbonate and related compounds.

Calcium carbonate is the compound most extensively used to reduce soil acidity, and this is probably because of the numerous deposits of limestone which are found practically throughout the world. Related compounds such as dolomitic limestones are applied in some areas where deposits occur. Success has been claimed for dolomitic limestone in Germany and U.S.A., where it is said to meet a magnesium deficiency of certain soils. Burnt lime, or CaO, is applied to a certain extent, and is noted for giving a more rapid response than the carbonate. It contains 47% of pure calcium, compared with 32% carbonate, when the crude stone contains 80% of $CaCO_3$, and consequently is more effective

bulk for bulk. It has a partial sterilizing effect on the soil, and is extremely unpleasant to handle. Results are usually obtained more quickly from burnt lime than from ground limestone, but there is no evidence to show that equivalent quantities of calcium are ultimately more effective in reducing soil acidity as the oxide, than as the carbonate.

(2) Calcium silicate.

Calcium silicate has been used to a small extent to reduce soil acidity in certain sections of the U.S.A., where it is produced as an industrial by-product. It is perhaps worthy of mention that despite a greater molecular weight than that of calcium carbonate, it has been proven to possess on some soils at least a greater capacity for reducing soil acidity than the carbonate.

CHAPTER II - THE PLACE OF LIME IN AGRICULTURE

A. THE PRACTICE OF LIMING.

(1) Historical.

The practice of liming the land has been carried on in some farming countries of the old world for centuries. The procedure adopted was to apply marl by carting it out and spreading over the land with shovels. The very nature of the method limited the early applications to small areas which received heavy dressings, with long intervals between each. During recent years, hand spreading has been almost completely displaced by efficient broadcasting machines, and with this change there has developed a tendency to replace the widely spaced heavy dressings with smaller dressings applied more frequently.

(2) The Influence of Lime on the Soil.

The influence of lime on the soil may be conveniently considered under three main headings, physical changes, chemical changes, and biological changes.

(a) Physical Changes.

As previously pointed out in the discussion on the development of acidity in soils, (p), the properties of acid soils are largely determined by the proportion of hydrogen ions to bases in the exchange complexes of the soil colloids. Strongly acid soils are difficult to cultivate because colloidal clay particles in which the hydrogen ion is dominant do not form a water stable crumb structure. Instead, they tend to remain in a deflocculated condition, and to produce on wetting a sticky impervious waterlogged soil which, on drying, cracks badly. Cultivation practices can only be carried out over a narrow range of soil moisture contents, and it is almost impossible to produce a satisfactory tilth.

The addition of lime to these soils results in a slow displacement of the hydrogen ions from the colloids by calcium ions. This change over from dominantly hydrogen colloids to dominantly calcium colloids, is accompanied by a marked improvement in crumb structure which is clearly reflected in the physical properties of the soil. It drains more freely, is more retentive of water in dry weather, develops a tilth more rapidly and can be cultivated over a wider range of soil moisture contents. To the farmer, these changes can be summarized in one word - the soil becomes more "kindly".

(b) Chemical Changes.

The addition of lime to the soil reduces the hydrogen ion concentration and markedly increases the active calcium available in the soil, (p). The extent to which the hydrogen ion concentration is reduced as mentioned on p. and is dependent not so much upon the "active" acidity of the soil as upon the "potential" acidity. Thus the same application of lime to a highly buffered soil will produce a much smaller change in the reaction than it would give on a slightly buffered soil.

The increase in the amount of active calcium in the soil as a result of liming, produces various important secondary effects. Thus iron and aluminium become less soluble, and their toxicity, particularly of aluminium, is reduced. The effect of the reduced solubility of iron and aluminium compounds on soil phosphate is important, for it has been considered that, under very acid conditions, soil phosphates and mono-calcic phosphates added to the soil may react with the iron and aluminium and produce compounds which, because of their low solubility, are unavailable to plants.* The addition of calcium to the

* This explanation has been considered inadequate to cover all the facts, and Marshall ( ), has suggested recently that the phosphates not only react with soluble iron and aluminium compounds to give colloidal precipitates, but that they also undergo anionic exchange with the clay complex.

soil protects both potassium and magnesium against loss by leaching, as shown in the extensive lysimeter experiments at Knoxville, Tenessee, (MacIntire, Shaw and Young,).

Russell ( ) and Magistad ( ) consider that it does not release potash from its insoluble compounds as was thought formerly. Jenny and Slade ( ) re-investigated the K-clay - $CaCO_3$ interchange with purified colloids and natural and artificial soils, and found that in all, lime liberated potassium in large quantities. Under favourable conditions for microbiological activity, they found that the addition of limestone actually caused a reduction of the potash content of the soil solution below the value of unlimed soil. They conclude that "the occasional observations of the lack of potassium solubility and availability after liming are not necessarily violations of the general base exchange principles, but may be the result - in part at least - of interference by micro-organisms."

(c) Biological Changes.

Organic matter tends to accumulate on acid soils, due to the reduction of activity of micro-organisms. The addition of calcium to such a soil causes marked stimulation of the micro flora and fauna. Bacteria, especially the nitrifying organisms, are sensitive to the conditions associated with high soil acidities, and do not thrive well in soils with a pH below 5·5. Similarly, earthworm activity is very much reduced on acid soils. (Aston). The result of the increased biological activity promoted by the application of lime is to accelerate the decomposition of organic residues added to the soil.

The circuit of plant nutrients from the plant to the soil by way of the organic residues and back to the plant again, is speeded up under the conditions induced by liming. The increased rate of circulation of the nutrients provides a quantitative increase of the essential elements to meet the increased

plant growth which results from the application of lime to acid soils.

In addition to these primary effects of liming on the biological activity, various secondary effects are brought about. Thus the causal organisms of corky scab on potatoes are various species of Actinomyces (Heald), belonging to the Actinomycetales, one of the orders of higher or filamentous bacteria. As bacterial activity tends to decrease as soil acidity increases, strongly acid soils are relatively free from potato scab. The application of lime, therefore, causes increased incidence of the disease by reducing the acidity; a fact well known to the practical man.

The opposite effect occurs with the causal organism of club root of cruciferous plants, Plasmodiophora brassicae, (Heald). This slime mould, in common with most other fungi, flourishes under acid conditions, and therefore the application of lime affords a practical means of control. This has been effectively demonstrated by Gibbs, ( ).

(3) The Influence of Lime on Crop Plants.

The lime status of the soil is reflected to a large extent by the vegetation growing on it. Indeed, so close is this relation under undisturbed conditions, that it has been used as a basis for the classification of plants. Ranges on the pH scale, over which each species makes thrifty growth, have been drawn up. This has been undertaken in several countries, and by numerous investigators who have developed the growth ranges of associations of weeds and native species, and of economic crop plants. Although the ranges for crop plants are fully discussed in section it may be mentioned at this juncture that many of the leguminous plants, (e.g. lucerne and red clover), have a relatively narrow range within which they will make good growth. On soils which are slightly more acid than the limits

indicated for thrifty growth, these plants may make stunted growth, and on more strongly acid soils, are usually entirely absent.

Co-incident with the change in acidity brought about by liming, there is often a change in the vegetation and plants such as the clovers, which make optimum growth only over a narrow range, are stimulated. An excellent illustration of this was obtained during the present investigation. (p.).

In addition to this effect of the lime status of the soil on the composition of the plant associations, mention must also be made of its influence on the composition of the plants themselves. Although some investigators have obtained negative results, (p.), it would appear from the great bulk of the evidence that the higher the lime status of the soil, up to certain limits, the higher the calcium content of the vegetation.

(4) Factors Influencing the Effectiveness of Lime Applications

Many factors influence the effectiveness of lime applications in reducing soil acidity, and among the most important of these are the quantities applied, the nature of the stone, its purity, and its fineness of grinding.

(a) The Quantities Applied.

The change in the reaction of a soil consequent upon liming is, of course, greatly influenced by the quantity of lime applied. Thus the heavier the dressing, the greater the change in acidity. However, the extent of the change is also influenced by the nature of the soil itself, and in this connection, the greater the buffering capacity of the soil, the less will be the change.

Not only the size of the component dressings, but also their frequency, influences the change in reaction. Thus a large single dressing will have less total effect over a period

of years than the same quantity applied as smaller dressings, dispersed equally over a similar period. This is the system practised over most of the North Island, and is supported by scientific evidence. Thus MacIntyre, Shaw, Ellett and Hill ( ) report a series of experiments, in which a comparison of losses of calcium were made on several soils, with single and multiple dressings equivalent to 2000 lbs. of burnt lime. In one case, the 2000 lbs. of CaO was applied to the top three inches at the beginning of an eight year period, and in another at the rate of 250 lbs. CaO at the beginning of each year. The results showed a smaller loss of calcium for the yearly applications in every case, the difference varying with the soil type.

(b) The Purity of the Stone.

The standards of purity for limestone are based upon the calcium carbonate content. This is, of course, directly related to the calcium content, so that the purity of the lime sample markedly influences the effectiveness of the lime applied. Good limestones contain more than 80% pure calcium carbonate, medium 70 - 80%, and inferior below 70%.

(c) Mineral Character of the Stone.

By this is meant the hardness or softness of the stone. This, with but a few exceptions, varies with the calcium carbonate content, which is highest in the hard limestone. Mineral character as it effects the availability, is discussed under fineness of grinding.

(d) Fineness of Grinding.

The importance of the fineness of grinding of a limestone sample on its rate of solubility* has been extensively studied in the U.S.A. American standards quoted by Grimmett

* Grimmett and Denz ( ) record experimental data proving this contention in an article published in Industrial and Engineering Chemistry, Sept. 1932. "Plots were treated with crushed limestone of definite particle size, and the amount used up was determined at 12 monthly intervals. It was found that for the initial period, particles passing a 48 mesh and retained on a 65 mesh sieve dissolved ten times as quickly as particles passing a 4 mesh, and retained on a 6 mesh sieve."

and Denz ( ) are for 100% passing a sieve of 60 meshes to the linear inch, and 70% passing a 100 mesh sieve. Gustafson ( ), suggests that while the finer material is available more quickly than the coarser material, there is an economic limit to fineness of grinding, and he suggests that 50% should pass the 100 mesh, and 90% pass the 20 mesh sieves. Hibbard ( ) states that material passing the 60 mesh sieve is fine enough. This may be the case on heavy rainfall areas, since under these conditions, the rate of solution must be markedly increased.

The mineral character of the stone is closely inter-related with fineness of grinding. Pot experiments at Cornell (which are described by Grimmett and Denz ( )), in which the effectiveness of different types of ground limestone was studied, showed that with a soft limestone the maximum yield was given by the 50 to 80 mesh to linear inch fraction, while the yield with the 25 to 50 mesh was nearly as great. There was a marked reduction in the response to the 10 to 25 mesh fraction. A slight reduction with material passing the 200 mesh sieve was believed to be due to mechanical leaching of this fine material, and serves to indicate that fineness of grinding can be carried too far. With a hard limestone, the maximum effect was not obtained until material passing the 100 mesh sieve was used, while that below 40 mesh proved comparatively ineffective. It would therefore appear that hard limestone should receive finer grinding than softer stone, if the same effect in reducing soil acidity is to be obtained within the same time.

(e) Summary.

The amount of soluble calcium developed from a given addition of limestone to the soil, depends on a number of factors:

(1) The purity of the limestone. This functions as : -

(a) The actual amount of calcium applied,
(b) The amount of inert material, or impurities

present: this tends to coat the particles and lower the rate of solubility.

(ii) The fineness of grinding: the more finely ground, the more speedily is the sample available. This applies over all the degrees of fineness likely to be found in commercial stones.

(iii) The softness or hardness of the stone: the harder the stone, the finer must the sample be ground to give the same availability of the calcium contained.

B. THE USE OF LIME IN NEW ZEALAND.

The use of lime in New Zealand will be discussed under four main headings: - historical development; methods of application; quality of New Zealand limestones; and experiments conducted with lime in New Zealand.

(1) Historical Development.

Liming was practised to only a small extent in the early days of New Zealand's agricultural development. The practice was almost totally confined to Otago and Southland, and the method adopted was similar to that used in England, i.e., heavy dressings at infrequent intervals. Thus Wild ( ) records that it was a general practice to dump sufficient shell lime on the field in the autumn to provide for the equivalent of a dressing of 2 tons per acre. The lime was left to slack in the dump over the winter, and was spread with shovels during the following spring.

About 1915, the custom of applying ground burnt lime at the rate of one ton to the acre began to develop, and for a time a controversy raged as to the relative merits of ground and burnt limestone. Except in special cases, results with ground limestone, although not obtained so quickly as with burnt lime containing calcium in equivalent quantities, were just as good over a longer period. The outcome was that the cheapness and better handling qualities of the carbonate prevailed, and ground limestone is now applied over the greater part of the areas limed in New Zealand.

As agricultural implements improved, the application of lime increased, but was still confined chiefly to Otago and Southland. The 1917 Official New Zealand Year Book gives us the first precise information on the quantities of lime used in New Zealand at this period. The production and usage of agricultural lime in New Zealand has, with the brief exception of the recent economic depression, steadily increased since the first records were taken. This is clearly shown in Table III (p. 23), which has been compiled from the statistics given in the Official Year Books for the periods 1917-37. A notable feature brought out in this table is the rapid increase in the use of lime in the North Island during recent years. Whereas formerly the North Island used only small amounts of lime, it has now almost reached the South Island totals.

The data available on the acreage limed each year is rather scanty, and seems to be confined to reports given in the New Zealand Journal of Agriculture during the period 1928 - 1933. From these reports, it would appear that the heavy infrequent dressings which were formerly in vogue have been largely replaced by smaller and more frequent dressings. This is particularly the case in the North Island, whose totals have increased markedly during recent years, due, no doubt, to the more general realization of the value of lime as an annual top dressing, both in reducing soil acidity, and in increasing the efficiency of the superphosphate applied with it.

The most recent information on the use of lime in New Zealand is condensed in Table IV (p.24). This shows that Auckland and Southland now lime the greatest area each year, while Southland, Auckland, Otago, Wellington and Canterbury, in this order, are the greatest users of lime. Nelson, Otago, Southland, Wellington and Marlborough, apply the largest average dressings.

The Annual Production of Agricultural Limestone over the Period 1917 - 1936.*

	1917	1920	1925	1930	1931	1932	1933	1934	1935	1936
Auckland,	4,746	33,867	20,865	55,007	56,049	63,003,	69,071	78,599	80,892	92,296
Hawkes Bay,	-	-	10,692	15,090	15,831	19,678	16,834	27,793	26,080	27,006
Taranaki,	-	18,720	-	3,441	2,900	4,002	-	877	-	4,148
Wellington,	-	-	8,689	12,695	8,847	8,930	-	8,603	8,022	9,326
Nelson,	-	-	-	-	-	-	-	-	-	-
	-	1,654		-	-	-	-	-	-	-
Westland,	-	-	-	-	-	-	-	-	-	-
	1,312	-	2,601	5,684	6,066	6,628	5,452	5,763	6,820	7,796
Marlborough,	-	-		-	-	-	-	-		
Canterbury,	2,644	11,916	4,885	-	-	-	-	-	-	-
	-	-		112,894	81,466	99,494	100,531	140,305	166,745	176,483
Otago,	36,501	-		-	-	-	-	-	-	-
	-	76,095	86,957	-	-	-	-	-	-	-
Southland,	24,958	-		-	-	-	-	-	-	-
Grand Total,	70,161	142,252	134,689	204,811	171,159	201,735	191,888	261,940	288,559	317,055
North Island Total,	4,746	52,587	40,246	86,233	83,627	95,613	85,905	115,872	114,994	132,776
South Island Total,	65,415	89,665	94,443	118,578	87,532	106,122	105,983	146,068	173,565	184,279

* Figures in tons of ground limestone and compiled from records given in the New Zealand Official Year Book for the years quoted.

The Utilization of Agricultural Lime in the Major Districts of New Zealand.
Period 1928 - 1932.*

Land District	1928 - 1929			1929 - 1930			1930-31	1931-32
	Area in acres	Dressing in cwts.	Av. Dressing	Area in acres	Dressing in cwts.	Av. Dressing	Area in† acres	Area in† acres
North Auckland,	17,134	80,419	4·7	26,637	105,330	4	54,727	52,839
Auckland,	56,224	158,028	2·8	134,297	411,045	3	168,926	187,351
Gisborne,	1,456	7,030	4·8	2,050	6,550	3·2	1,835	913
Hawkes Bay,	2,843	15,146	5·3	7,827	35,510	4·5	9,223	9,386
Taranaki,	12,486	42,096	3·4	17,409	47,097	2·7	32,862	26,870
Wellington,	16,837	101,425	6·2	26,073	199,753	7·7	39,761	38,513
Nelson,	2,745	27,850	10	3,063	32,669	10·7	6,362	4,617
Marlborough,	633	4,401	7	816	6,018	7·4	1,847	842
Westland,	1,348	8,825	6·5	2,408	10,974	4·5	3,504	3,780
Canterbury,	13,092	76,094	5·8	34,391	180,140	5·2	40,681	21,216
Otago,	21,027	231,653	11·0	21,508	215,024	10·0	23,114	10,631
Southland,	77,548	604,439	7·8	83,184	629,761	7·6	56,036	29,791
Total,	223,373	1,357,406	6·1	359,663	1,879,871	5·2	438,878	386,649

* Data compiled from Journal, Dept. of Agriculture, 1928-1933.

† Area only, available in 1930-1932.

(2) Methods of Application.

The methods of applying lime have steadily improved from the initial method of carting the lime out in drays and spreading it with shovels. The first change was the introduction of the horse drawn top-dresser and,this too, has in recent years been superseded in suitable areas by motor-lorry dressers.

At the present time, the methods of application vary with the nature of the country, and the inclination of the farm owner. On areas which are flat enough and dry enough, the motor-lorry with top-dresser attached is becoming very popular. This method, which saves double handling, is both rapid and economical. On wet areas the horse-drawn top-dresser is used, but the method is slower and more laborious than the lorry top-dresser, and in addition, involves double handling of the lime. On areas too steep for the motor-truck, horse top-dressers may be used. Of recent years the work on these areas has been speeded up in some instances by the use of top-dressers drawn behind caterpillar tractors. Hand top-dressing with lime may be done to a small extent, but the bulk of a satisfactory dressing makes distribution by this method too costly.

In addition to the quantities of lime used alone as a top-dressing, there is approximately 20,000 tons mixed with superphosphate, for drilling with rape and turnip seed to prevent germination injury. (N.Z.Official Year Book).

(3) The Quality of New Zealand Limestone.

(a) The Purity.

The purity is determined by the amount of pure calcium carbonate present in the ground rock. Bruce ( ) in a review of New Zealand limestones gives analyses of samples from twenty-four works not served by rail. The percentage of carbonate in these samples varied from 41·75% to 97% and averaged 81·69%. Analyses of samples from forty works whose lime was

carted by rail ranged from 59·86% to 95%, and averaged 83·57%. With a few exceptions, then, New Zealand commercial limestones have a fairly high calcium carbonate content.

As previously stated, (p.), hard limestones must be more finely ground than soft stones to give the same availability of the calcium contained. New Zealand limestones have, with but minor exceptions, a hardness closely related to their calcium carbonate content.

(b) Fineness of Grinding.

All New Zealand writers on lime, (Grimmett and Denz, Bruce, Hopkins, Woodcock), stress the importance of the average fineness of grinding on the rate of solubility of the lime, but all propose different standards as being most suitable. All agree that the fine material acts more quickly than does the coarse, and that, therefore, the coarse material represents, to a certain degree, capital lying idle. This, however, may not be a disadvantage on acid soils in heavy rainfall areas.

Since no required standards of fineness have yet been set in New Zealand, the commercial samples of ground lime show wide variations in the percentages of fine and coarse materials. Analyses of fineness of grinding were made by Grimmett and Denz ( ), on a number of samples, and they obtained the following average results.

TABLE V

Average Results of Fineness of Grinding of Commercial Limestones obtained by Grimmett and Denz

Retained on sieve with 10 meshes to linear inch,	A considerable portion - up to 20% in some cases
" " " " 60 " " " "	50%
" " " " 120 " " " "	75%

Bruce gives similar results for what he considers to represent a typical New Zealand limestone. These results, when compared with the American standards, would show most New Zealand limestones as being slightly coarse. It would appear, however, that these ground limestones are perfectly satisfactory for high rainfall areas, but should be more finely ground when applied to drier areas, such as North Otago, and parts of Canterbury.

C. EXPERIMENTS WITH LIME IN NEW ZEALAND.

Experiments carried out with lime in New Zealand have been along two lines of thought, and are accordingly dealt with under two headings:

(1) Trials where lime responses are measures,

(2) Trials where lime responses are correlated with lime requirements.

The first of these divisions is by far the larger, and includes (a) observational trials, (b) yield trials, and (c) chemical trials measuring the effect on herbage quality.

Trials in the second section, although much .. smaller in numbers, are probably more important, as they attempt to provide information on lime responses, as based on the .. chemical properties of the soil. Trials in the first section can give as their results only the type of response obtained, and the liklihood of obtaining it, whereas trials in the second section, by a correlation of field responses with the lime status of the soil as determined by one or all of the accepted lime requirement methods, attempt to arrive at the fundamental reason for responses and non-responses.

(1) Trials in which Lime Reaponses are Measured.

(a) Observational Trials.

A most comprehensive series of these trials was carried out all over the country by the New Zealand Department

of Agriculture. (Woodcock). Six hundred observational plots were laid out with a complete manurial trial on each. This included lime applied at the rate of 1 ton of carbonate per acre. The results for lime alone and super plus lime are extracted and summarized by Woodcock ( ), who divides the responses recorded into three groups. These are briefly discussed below.

Group I. In this group super alone gives poor, or only fair, results; lime alone may give fair, to good, results; superphosphate with lime gives good, to very good results.

In this class, growth of both grasses and clovers is poor on unlimed ground, but lime, in conjunction with superphosphate induces a striking improvement in white clover, which is often reflected in the increased vigour of the ryegrass.

The palatability of the herbage on the limed plots is generally better than that on the unlimed plots. Liming is essential on this class of land.

TABLE VI

Land District Classification of Responses to Super and Lime obtained in Observational trials.*

District	Soil	Percentage of Experiments in Group I
N. Auckland,	Clay or silts,	92
N. Auckland,	Ironstone (laterite)	100 (2 experiments
"	Volcanic,	71
Marlborough,	Loams and sandy loams,	33
Westland,	Miscellaneous,	90
N.Canterbury,	Silt loams and loams,	43
Christchurch,	Sandy silts and silt loams,	41
Mid-Canterbury,	Fine sandy silts and silt loams,	61
S.Canterbury,	Clay loams and silt loams,	30
S.Otago,	Miscellaneous,	33
East Southland	"	60
West Southland	"	11

The small proportion of experiments showing responses in South Otago and Western Southland is considered by

* Woodcock (

Woodcock to be due to the fact that lime had already been applied to many of these areas.

Group II. Super gives good results, but better results are obtained from super with lime. Experiments are generally on better pasture than in Group I.

Lime responses are generally spasmodic, appearing most frequently in the autumn, when white clover growth is more pronounced. Lime is not essential for the establishment and maintenance of reasonable pasture, but lime as an adjunct to super, will increase production. Experimental results falling into this class have been obtained in most districts, but more particularly in the King Country, S. Taranaki, Wanganui, Marton, Wairarapa and N. Manawatu districts in the North Island, and on Banks Peninsula in the South Island.

Group III. The addition of lime to super gives no appreciable improvement over super alone.

Although isolated trials of lime + super, which have been classed into this group, may show slight but fleeting responses, the majority of these experiments do not indicate any improvement in the amount of growth, composition of the sward, or palatability of the herbage. Districts so classified are: Rotorua and S. Waikato, (punice soils), Hauraki Plains, (clay soils), Southern Poverty Bay, Hawkes Bay, S. Manawatu, N. Otago, and Central Otago.

Extensive manurial trials were carried out in Canterbury by Hudson and Montgomery ( ). Two hundred and one observational trials were established, and the responses recorded in Table VII were obtained from dressings of one ton of carbonate and three cwt. of superphosphate per acre. The relation of the responses to super + lime to those of super alone are worth noting.

TABLE VII

The Percentage Classification of Responses to Lime and Super obtained by Hudson and Montgomery in 201 Observational Trials

	No visible response	Doubtful	Slight	Fair	Good	V.Good	Excellent
Lime alone, 1 ton of carbonate,	5	5	29·5	28·5	26	6·5	-
Super alone, 3 cwt.	5	3·5	26·5	33	24	7·5	1
Lime + super,	2	4	6·5	12	23·5	23	29·5

Montgomery (Hudson and Montgomery) observed the effect of lime on some soils four to five months after the application had been made, but generally speaking, the effect was more apparent in the second year, than in the first.

All writers agree that the effect of lime persists in the soil for at least six years. Woodcock ( ) instances cases of Canterbury pastures where applications of one ton of limestone in 1928 were clearly visible in 1935. A one ton strip application at Winton in 1924 could still be discerned in 1934. This experimental evidence supports a belief long held by the practical man.

Woodcock reports that lime gives relatively high responses during periods of low production, and practically all investigators report an increased percentage of clovers in pastures after applications of lime to acid soils.

Observational trials give a measure of the liklihood of a response to lime being obtained in a particular, and as such, are valuable for mapping on a broad scale. They do not seek to explain the soil differences which give rise to responses and non-responses, and so make no advance in the direction of forecasting with greater accuracy the results which should be obtained from lime on any particular area.

(b) Yield Trials.

There have been only a small number of yield trials

in which lime alone is compared with no lime. A.W.Hudson ( ) carried out several such experiments at Tai Tapu, and in North Canterbury, and obtained some significant and some non-significant increases. Askew and Rigg at Nelson ( ) in a similar trial using Hudson's alternate grazing and mowing method obtained significant increases in yield on their limed areas. Greenwood ( ) in Marlborough, and Patterson (at Auckland, also obtained significant increases for lime alone, over no lime.

Yield trials involving lime alone compared with no lime, have been few in number, and varied in response. Better results have been obtained from yield trials in which lime and super has been compared with super alone. Significant increases in favour of the lime + super are recorded by Hudson and Montgomery ( ), Patterson ( ), A.W.Hudson ( ), Tennent, ( ), McGillivray ( ), and Rigg and Askew (

On the other hand, the results of the Field's Division trials carried out from 1924 - 29, and summarized by Woodcock, are not so encouraging, for only seventeen trials out of 46, or 37% show appreciable increases.

Yield trial experiments have been relatively few in number in comparison with the area of land likely to want lime in New Zealand. Like observational trials, they are an empirical method, and serve only to indicate the degree of probability of obtaining a response, and the possible size of the response if it be obtained. Nevertheless, they serve as an admirable approach to the problem.

(c) Experiments on Herbage Quality.

A general impression exists among the farming community that lime is beneficial to stock, and its application is good farming. Woodcock ( ) terms it the "lime complex" of the farmer, and considers that lime exerts "a subtle influence on the chemical composition of the herbage." This point of view

is also expressed by Hudson and Montgomery ( ) who state "From the point of view alone of increased benefit to stock, in supplying lime through the medium of pastures, the writers are of the opinion that its use is justified on all Canterbury pastures." They also indicate that where field results provide no visible evidence of a response to liming, invisible changes may take place in pasture growth, which may so beneficially affect stock as to make liming worth while.

In order to study this question, several trials, in which the herbage from limed plots was compared with that from unlimed plots, have been carried out in this country. Rigg and Askew ( ) found no increase in the calcium content of the herbage as a result of lime applications, but the potash and nitrogen content of the herbage was increased. Woodcock (cites figures supplied by Doak in which an application of lime increased the CaO content of the herbage from 1·15% to 1·24%. The increase is not unexpected, as the limed plots contained a greater proportion of white clover which, according to Doak, contains almost twice as much calcium as ryegrass.

Hudson and Doak ( ) consider that the increased lime content of the herbage due to the application of superphosphate to be not entirely due to the increase in the clover content. It seems reasonable to assume that this would also be the case for lime applications. This is supported by the work of Aston ( ), who records liming as increasing the calcium content of pastures, and thereby relieving deficiency diseases in the Mairoa district of the North Island.

(2) Trials in which Lime Requirements are Correlated with lime responses.

As has already been mentioned, the system of testing for lime responses by means of observational trials and herbage yield trials, has some marked limitations. In addition, considerable time has to elapse before conclusions can be drawn.

Reflections on the accuracy of the methods employed have been made, and these are well summarized by Dixon (in a review of what he terms "hit or miss" methods. This review is given as follows : -

(1) Observation methods liable to a 20% error.

(2) Low growing clovers are not by mowers.

(3) Different types of grasses and clovers do not respond to the same extent on the same land. A red clover response would be more readily measured than a white.

(4) Mowing method takes no account of the increase in quality e in a pasture.

Chemical methods have been sought which obviate these difficulties, but success so far has been small. The Hutchinson, MacLennan method for the determination of lime requirements is used by the following investigators.

Patterson ( ) finds a correlation between lime requirement and lime response on one out of two Auckland soils tested. Hudson ( ) finds little correlation on several N. Canterbury and one Tai Tapu and one Prebbleton soil. Neither of these investigators has attempted to follow out changes in soil acidity following the addition of limestone, and, correlations when sought, are between original lime requirements and field responses on varied soil types. There seems to be little correlation between the two.

By far the most intensive investigation correlating lime requirements with lime responses is that conducted by J. K. Dixon ( ). Dixon attempted to correlate lime requirements with lime responses by collaborating with the Department of Agriculture in 44 yield and observational trials in the South Island. Observational and yield responses were standardized against lime requirements. Lime requirements methods are excellently reviewed by Dixon, who finally selected eight of the methods which he considered most likely to be successful. These were : -

(a) Measurement of lime absorption by the soil.

(1) Hutchinson and MacLennan ( )
(2) Hardy and Lewis (

(b) Measurement of the available lime in the soil.

(1) Smith's ( ) adaptation of Hissink's replaceable base method.

(c) Indirect Methods.

(1) pH electrometric quinhydrone electrode and platinum and gold electrodes.

(2) pH colorimetric B.D.H. method.

(3) Replaceable hydrogen. Joffe and McLean's ( ) test.

(4) Comber's ( ) test for soluble iron.

(5) Truoy's ( ) test.

The correlations between lime requirements as determined by the above methods, and lime responses as determined by the field experiments of the Department of Agriculture, were widely variable. The Hutchinson and MacLennan was considered by Dixon to be the most satisfactory in that it combines accuracy with convenience. It gave only two exceptions in 38 soils with the methods of replaceable lime, and pH electrometric next each with 5 exceptions.

Dixon, however, considered that no single factor method was satisfactory, and proposed a ratio which proved entirely successful with no exceptions in 38 soils. This ratio was : -

CaO required. (Determined by Hutchinson MacLennan.)
CaO Replaceable.

Dixon's conclusions are extracted: -

"A sufficient number of soils have been examined by the methods of this group to make results reliable.

(1) Lime Requirement ($CaCO_3$) Hutchinson-MacLennan.
Response to lime (·17 - ·18%) No response to lime
2 exceptions in 38 soils.

(2) Replaceable lime (CaO).
No response to lime ·25% Response to lime.
5 exceptions in 40 soils.

(3) pH value (electrometric).
No response to lime (5·8 - 5·9) Response to lime.
5 exceptions in 38 soils.

(4) Ratio given by $\frac{\text{CaO required}}{\text{CaO replaceable}}$ (From Hutchinson MacLennan corrected figure).

Response to lime (·5 - ·6) No response to lime.
No exceptions in 38 soils. "

The ratio was later applied with success by Dixon ( ) in his lime investigations at Mairoa.

While this method provides an accurate means of determining whether the soil required lime or not, it gives no indication of the quantities required, and the extent of the changes which should result from applications of different quantities of limestone.

The method of determining field responses which was used by Dixon is open to question, and the single dressings of one ton of carbonate is unsatisfactory for so many diverse soil types. However, it is the first thorough investigation in New Zealand attempting to correlate lime requirements with field responses, and is deserving of the highest praise.

PART II

INTRODUCTION - AIMS OF THE INVESTIGATION.

The position of the results from liming experiments in Canterbury to-day is one of uncertainty. Responses to lime have, in most cases, been good, but a certain element of doubt exists as to whether a response will be obtained or not, and to how much lime will be needed to produce a response.

The purpose of this investigation is to remove this element of doubt. The first proposal is to deal with liming responses on definite soil types, as under this system uniform responses should be obtained, and uniform recommendations could be made, capable of being applied to the whole area falling within that soil type of land. Accordingly, four clearly defined soil types have been chosen as the basis of experimentation.

The second proposal is to apply a satisfactory lime requirement method, and to so correlate field responses with laboratory determinations, that a factor emerges, which can be used in future, in conjunction with laboratory determinations only, to faithfully portray field responses which would follow any lime applications on that defined soil type. In accordance with this, a new lime requirement method due to Christensen and Jensen ( ) and modified by Mitchell ( ) was chosen. This method portrays lime requirements of soils for any desired pH - an advantage not hitherto displayed by any other method. In addition, the lime requirements determined are compared with field responses, measured not by herbage weights which are notoriously liable to variation, but by pH changes in the soil itself.

It is also intended to investigate, as far as possible, the reasons for differential lime responses by determinations of colloid contents, and organic matter.

CHAPTER III - THE FIELD WORK

A. THE SOILS SELECTED FOR THE INVESTIGATION.

(1) Introduction.

No doubt exists about the origin of the great bulk of the material forming the Canterbury Plains. All authorities agree that they are derived from the greywacke rock forming the bulk of the Southern Alps, which has been transported by the great shingle rivers of the plains. (Grange Jobberns). Haast ( ) states, "We must conclude that the Canterbury plains are formed by the outlets of enormous glaciers, large torrents bringing down the morainic matter, thrown in their course at the terminal face, raising their beds and shifting their channels at the same time, so as to form fan shaped fluviatile accumulations, consisting of shingle, gravel, sand, and glacier mud."

However, surface deposits, although of similar origin,are deposited by different means. Soils of the Ashburton County are considered by Grange ( ) to have been deposited in two ways : -

(1) By rivers; which have been formed fairly deep alluvial soils in narrow strips along the river banks.

(2) By the nor-west wind, which has carried loess from mountain-top and dry river channels, and deposited it in thin layers over the large areas between the rivers.

Behind the plains are low downs of good farming land. This gradually passes back to higher ground, which merges into the foothills. Although the material forming the mass of these foothills may differ geologically, the surface deposits from which the soil is derived appear to have originated from greywacke, as wind blown loess. (Park

The pedological conception of the Canterbury Plains

is not complete, however, without reference to the coastal area of deep soils, built up by fine material deposited in quiet water, and containing, in many places, high percentages of organic matter. This coastal area, however, does not here concern us.

The climate of the Canterbury Plains is diversified. The areas of different rainfall are indicated on the map (A coastal area of thirty inches mean annual rainfall passes into a drier area of 25 inches or less. The rainfall then rises again towards 35 - 40 inches mean annual fall on downy country, and finally reaches 50 inches or more in the foothills.

Canterbury soils overlie a wide range of geological formations; their surface layers have been built up by various agencies of deposition, and they are subject to different climatic conditions. Accordingly the types of soils represented in Canterbury cover a wide range and show varying responses to the applications of lime and fertilizers.

(2) The Soil Types Selected, and the Reasons for Selection.

(a) Reasons for selection.

For the purpose of this investigation, it is essential that well-defined soil types should be selected, so that the information provided can be applied in the future to clearly demarcated areas. Consequently, two soil types, already defined by Grange, and two other clearly defined types, are chosen.

It is felt that it is desirable to choose soil types representative of the methods of deposition of Canterbury soils, and accordingly, the soils chosen are : -

(i) A wind-borne loess deposited shallowly in a shingle sub-soil.

(ii) A wind-borne loess deposited on a heavy clay sub-soil.

(iii) A deeper loess deposited on a less shingly sub-soil.

(iv) A water-sorted deposit.

The soil types selected are as far as possible representative of the agricultural areas of Canterbury in respect to mean annual rainfall. Further, farms are selected on which responses from lime are likely to be obtained, as indicated by previous experiments. This is the case on two of the soil types selected, while on the other two types, individual farms are well known on which good lime responses have been obtained.

The choice of soils is guided to a certain extent by experience. It is felt that the soil of the Moeraki type will respond to lime because of its pronounced acidity, as indicated by lack of clovers in the pastures, very bad tilth, and the presence of various weeds. The soils of the light land, although seemingly dry and far from acid, are inhabited by several plants typical of acid associations. The free drainage conditions of these soils suggests that acidity might be present to an unsuspected extent. The soil types in the Methven district are under a heavier rainfall, and under these conditions, it would be expected that acidity would develop. Plants characteristic of acid associations are present, especially nearer the foothills.

(b) <u>The Types Selected</u>.

(i) Stony silt loam over coarse gravel.

This soil type which is deemed to be representative of large areas of the plains round Rolleston and along the south bank of the Eyre river has a top-soil which varies in depth over a range of from 6 - 10 inches. Since the boundaries of the type have not been determined, it is referred to throughout as the light land type, and its area is indicated on the map (

(ii) Silty clay loam over heavy clay.

This type is representative of the Moeraki Downs, but is considered to extend over the Ashley river and north as far

as Amberley (see map). It is referred to throughout as the Moeraki type.

(iii) Stony silt loam and loam.

This type, which comprises four narrow strips between the Hinds and branches of the Ashburton rivers, has been termed by Grange ( ) the Buccleugh stony loam and stony silt loam. Since it is represented near Methven in the Ashburton County, it is referred to throughout as Methven, Type 7, and its extent can be gauged from the map (

(iv) Clay loam and heavy silt loam.

This type comprises a narrow strip of highly productive land running north and south through Methven township. It is referred to by Grange ( ) as Springfield clay loam and heavy silt loam, and on the Ashburton Survey is known as Methven, Type 20; a nomenclature which has been adhered to in this study.

(3) Detailed Description of the Soil Types Selected.

Each soil type will be considered under the headings of (i), General characters; (ii) Parent material and weathering, and (iii) Previous experiments with lime on farms within the soil type.

(a) Light land type.

(i) General characters.

This type of soil extends over approximately 72,000 acres on the south bank of the Eyre river, and is also represented by a large circular area of approximately 82,000 acres between the Selwyn and Waimakariri rivers. An area of 100,000 acres on the north bank of the Rakaia, is considered to be of similar type, and accordingly is so classified.

The soil is a stony silt loam over coarse gravel, and the depth of top-soil varies from 6 - 10 inches. The soils

drain freely and can be worked as soon as rain ceases. Water retention is poor, and the soil usually dries out badly during the summer months. On close examination, the soil appears to contain a high percentage of the fine fraction, and lack of water retention and free drainage would appear to be due not to the coarseness of the texture of the soil material, but to the thinness of the layer of soil overlying the coarse gravelly subsoil.

(ii) Parent material and weathering.

The parent material of this soil type is a loessal deposit of fine grained detritus of greywacke rock, which has been transported by wind and deposited over the large areas between the rivers.

The light land areas are chiefly in the light to moderate rainfall areas, (see map p.), and accordingly, one would not expect podsolization to develop rapidly. Furthermore, the vegetation of the Canterbury Plains before being broken up belonged to the low tussock grassland association, (Cockayne and most grassland associations do not promote rapid podsolization, (Russell). However the rainfall, though small annually, is periodically heavy (Grange) and this, combined with the thin soil, gives a much greater leaching than would have been supposed from a consideration of the annual rainfall figures. Grange finds evidence of podsolization to a small extent in similar soils in the Ashburton County, and terms the soils weakly podsolized.

Evidences are that weak podsolization has occurred on the light land soil type now being studied.

(iii) Previous Experiments with lime on the soil type.

Results of previous trials on the light land have been distinctly encouraging. The only experiments involving lime alone which have been carried out on the light land are those of

Hudson and Montgomery ( ). These writers express the opinion that some of the highest responses to lime occur on the light to medium soils overlying shingle, such as those in the vicinity of Sherwood and Lauriston. Responses from lime were rated by Hudson and Montgomery on the following scale: -

0	=	No visible response.	3	=	Good response.
?	=	Doubtful response.	4	=	Very good response.
1	=	Slight "	5	=	Excellent ".
2	=	Fair "			

A response of 3 is high for lime, as 4 appears only very occasionally. Five appears fairly commonly in the super + lime responses.

Experiments in the area on the south bank of the Eyre river gave responses as follows : -

Farm	Dressing of Lime	Dressing of lime + super
J.E.Burns,	1	3
W.S.Busch,	1	3
H.G.Cross.	3	5

A plot on the present light land series has been located on the farm of J.E.Burns.

Responses in the Kirwee-Rolleston area were obtained at the rate of : -

Farm	Dressing of Lime	Dressing of lime + super
M.V.Davis, Aylesbury,	1^{+}	1
A.Manson, Kirwee,	1	2
J.D,Penny, Kirwee,	2	3

The farm of M.V.Davis is close to a plot established in the present investigation, which is situated on the farm of F. W. Lill. Responses on this type of country in the Te Pirita - Mead Settlement - Bankside district were from 0 - 3 for lime, and from 1 - 5 for super + lime.

On the whole, results obtained on the light land, although in some cases variable, have been better than would be expected from casual consideration of the soils.

(b) Moeraki Type.

(i) General Characters.

What is considered to be the most typical soil on this type extends over an area of approximately 17,000 acres in an area between the Cust and Ashley rivers. A small area of approximately 3000 acres of similar soil reappears on the south side of the Cust valley, between Springbank and Cust. On the north band of the Ashley river, a similar soil type again appears and runs northward almost as far as Amberley, and covers an area of about 60,000 acres.

The soil is a silty clay loam, ten to twelve inches deep, and overlying heavy clay. The soils are poorly drained and hard to cultivate. Drawbar pull is very heavy, and a satisfactory seed bed is hard to obtain unless the land has been lying up to the weather for some time. Water relationship are very poor: the land becomes waterclogged and practically unworkable in wet weather, and cracks badly in dry weather, due to the finely textured soil resting on impervious sub-soil. Drainage is by run-off rather than by percolation through the deeper layers. An idea of the physical properties of the soil can be gathered from the fact that practically no winter wheat was sown on this area during the wet winters of 1936, 1937, and 1938, while during the dry years of 1931 and 1932, the ground dried out badly, and huge cracks formed.

Clovers are almost entirely absent from pastures which have not been limed, and weeds of acid associations, such as sorrel and spurrey, are present in large quantities, especially in favourable environments, such as wheat stubble, or young turnip crops.

(ii) Parent Material and Weathering.

The underlying rock of this area is considered by Haast ( ) to be either of litteral crigin or to be shallow

water deposits. The Moeraki Downs appear to be at a junction of the Oamaru and Pareora formations, as it is stated by Haast ( ) that south of Mt. Brown, the Oamaru beds partly surround Mt. Grey, and continue to the southern banks of the Ashley river, where their traces are lost. However, whatever the origin of the lower strata, it seems reasonable to assume from the topography of the country that the surface layer from which the soil is derived has arisen from wind blown loess, and this conclusion is supported by Park ( ) who states, "Further north, the loess spreads over a large portion of Banks Peninsula, and the Downs rising from the Canterbury Plains at the foot of Mt. Grey, reaching as far as the Ashley and Motunau Downs. It is well represented in the Malvern Hills."

Most of the Moeraki type is in the 30 - 35 inch mean annual rainfall belt, with some of the higher areas under 40 inches. Rainfall is relatively high by comparison with the light land areas, and therefore the acidity developed in the soils should be correspondingly greater. Portions of the original vegetation left in the gullies and steep unploughed patches indicate that the original cover was dominated by plants belonging to the low tussock grassland association which covered the major portion of Canterbury two centuries ago. Accounts from early settlers, supported by evidence from some of the gullies, indicate that at least a portion of the area was covered by manuka scrub; an association under which high soil acidity develop.

(iii) Previous Experiments with Lime on the Soil Type.

No liming experiments have been carried out on the Moeraki Downs which extend over an area between the Cust and Ashley rivers, and include all three of the experimental plots on this soil type. However, two experiments, giving very good responses, were carried out by Hudson and Montgomery ( ) on what is considered to be the same type of soil on the north bank of the Ashley river.

The results were:

Farm	Dressing of Lime	Dressing of lime + super
F.J.Douds, Amberley,	2	3
C.King, Loburn,	3	4

Just as the Ashley river cuts a path through the soil type, so does the Cust, and a small section appears on the south side of the Cust valley. It runs out at a point on Mr. Rand's property opposite the Springbank railway-station, but further west extends southwards for a mile or so. Excellent responses at the rate of lime 3, and lime + super 4, were obtained on this section of land by Hudson and Montgomery on the farm of Mr. S. Smith, Cust.

On the whole, it can be stated that, while the trials have been few in number on this soil type, responses have been universally very good.

(c) Methven, Type 7.

(i) General Character.

Type 7 covers an area of 47,200 acres (Grange between the Hinds river and branches of the Ashburton river. It is described by Grange ( ) as being in an area of mean annual rainfall of about 39 inches. This moderately high rainfall over a long period has induced sufficient leaching of bases from the topsoil to justify classifying the soil as being weakly podsolized. The position is made clear by the chemical report on the Ashburton soils (Rigg, Kidson and Hodgson) which states "Under high rainfall, soluble salts, lime, magnesia, and finally aluminium and phosphate compounds are leached from the top-soil. Marked deficiencies of lime and phosphate, accompanied by soil acidity, may thus result. The rainfall in the Ashburton County varies from 28 inches near the coast to 39 inches in the low hills north of Ruapuna, Mayfield and Cairnbrae. Even under a rainfall of 28 inches, these effects are visible in the profile of ancient loess soils, and these effects become more pronounced under the higher

rainfall in the north-western section of the country."

The soils belonging to this type vary from stony silt loam to loan, and range in depth from 15 inches to 19 inches. No particular cultivation difficulties are experienced in the preparation of a seed-bed. Clovers usually make only poor growth, especially on the farms near the foothills, where spurrey often partially smothers young turnip crops.

(ii) Parent Material and Weathering.

The parent material is all fine grained detritus of greywacke rock with tertiary rocks and rhyolite contributing a negligible amount. (Grange). The fine grained beds which give rise to the soil and sub-soil, rest on thick beds of closely packed gravel and sand matrix.

The surface layer of soil is described by Grange as being an ancient wind blown loess. The natural vegetation was of the low tussock grassland association which, according to Cockayne ( ) extended to a height of 1500 feet above sea level. This is supported by the evidence of unploughed gullies.

(iii) Previous Experiments on Farms within the Soil Type.

The only experiments which have been carried out on this type are those of Hudson and Montgomery ( ) on the farms of D. Campbell, Methven, and R.N.Elliot, Methven, where lime responses of 1+ and 1, and lime + super of 2 were obtained. From the position of Elliot's farm given on Hudson and Montgomery's map, there is some doubt that it is on this doubt.

In summing up this type, one would expect lime responses chiefly because the soil overlies a porous sub-soil, and is weakly podsolized, due to long exposure to moderately high rainfall. The limited number of liming experiments which have been conducted on this soil type do not indicate responses to lime as great as might be expected. However, the need for lime on these soils is supported by chemical evidence, (Rigg, Kidson,

Hodgson) who give results showing that samples from the farm of Robertson, Anama, have a pH of 5·33, and a lime requirement, (Hutchinson and MacLennan method) of 0·31%.

(d) Methven, Type 20.

(i) General characters.

The soil type extends over an area of acres (Grange) in a narrow strip running north and south through the township of Methven.

The total depth of soil and sub-soil is in most places more than 3 feet, and the soils vary in texture from clay loams at the southern end to heavy silt loams at the northern end, (Grange). Clovers appear to be present to a greater extent than on Type 7, but clover growth is not so vigorous as might be expected for the type of country, due, no doubt, to the acidity of the soil.

(ii) Parent Material and Weathering.

The parent material, climate and vegetation are similar to Type 7, but the method of deposition differs. Type 20 is considered to be of more recent origin than Type 7, and to have been deposited by an old flooding of the north branch of the Ashburton river. It is a relatively old water sorted deposit, but the influence of the parent material is still dominant, and Grange ( ) classifies it as a skeletal soil.

(iii) Previous Experiments with Lime on Farms within the Soil Type.

As far as can be ascertained, there have been no actual experiments carried out on this area, but good lime responses have been obtained by several farmers who use lime. The fact that the soil is classified as being skeletal would suggest that only a small amount of acidity would have developed. However, the soil is an old water sorted deposit in a high rainfall area, and this, together with the type of vegetation, suggests the need for lime.

This is supported by the chemical investigations of Rigg, Kidson and Hodgson who show pH values of 5·51, 5·35, and 5·34 respectively on the farms of F.W.Ruddenklau, Ireland, and McAnulty in this area. Lime requirements (by Hutchinson and MacLennan method) are given as 0·23% for both Ruddenklau and Ireland, and these, though showing less marked acidity than the figures for Type 7, certainly indicate a lack of lime in the soil.

B. THE EXPERIMENTAL BLOCKS.

The information regarding the experimental blocks is considered under the following sub-divisions: -

(1) Location of Plots.

(2) Previous History of the areas selected.

(3) The Treatments Applied.

(4) Size, arrangement and Replication of the Plots.

(5) Sampling the Plots.

(6) The Lime used in the Experiments.

(7) The Analysis of the Herbage.

(1) Location of Plots.

Although no particular attention was paid to the location of the farms on the four soil types chosen, they were selected so as to be reasonably far apart. This was done to give results representative, as far as possible, of the whole type. The location of the farms selected is shown on the map (

They are as follows : -

(a) Light land type.

Map No. 1,	Ashley Dene,	4 miles west of Springston.
" " 2,	F.W.Lill,	4 miles west of Rolleston.
" " 3,	J.E.Dums,	South Eyre Rd. 2 miles south of Horrelville.

(b) Moeraki Type.

Map No. 4,	E.Smith,	Moeraki Downs, Springbank.
" " 5,	V.O.Frizzell,	" " "
" " 6,	H.Sail,	" " Cust.

(c) Methven, Type 7.

Map No. 7,	Alec Wilson,	3 miles north of Methven.
" " 8,	H.E.Jessep,	6 miles north-west of Methven.
" " 9,	Charles Stockdill	5½ miles south-west of Methven.

(d) Methven, Type 20.

Map No. 10,	S. Holmes Estate,	"Mt. Harding", one mile north-west of Methven.
" " 11,	Andrew Wilson,	2½ miles north-west of Methven.
" " 12,	A.M.Leask,	Ashburton road, 2½ miles south of Methven.

With regard to the location of the plot on any one of the farms selected, particular care was taken, and each field in which a plot was established complied with the following requirements : -

(a) It must be sown in pasture which was to be left down for the following two years.

(b) If possible, it should not have been limed.

(c) It should be flat, or if this were not possible, it should have only a slight slope.

Further than this, the plots were so located that they were : -

(a) Free from feerings, finishes and headland furrows.

(b) They were not influenced by : -

(i) Shade from fences or trees,
(ii) Sheep camping grounds.
(iii) Old stack bottoms.

(c) They were well drained.

(2) Previous History of the Areas Selected.

The previous history of each field selected was traced, and is here summarized. It is regrettable that pastures of a similar type and age were not available for selection at the time of laying down of the trials, for this would have made possible more accurate comparisons of pasture composition. The histories of the fields were as follows : -

(a) Light land.

(i) Ashley Dene.

Year	Cropping Programme	Manuring
1933	Green feed, oats,	1 cwt. super.
1934	Pasture,	1 cwt. super.
1935	"	-

Year	Cropping Programme	Manuring
1936,	Pasture,	-
1937,	Sub. clover surface sown,	1 cwt. super.
1938,	"	-

No lime at any time as far as can be ascertained.

(ii) F.W.Lill.

Year	Cropping Programme	Manuring
1930-38	Sub. clover and pasture,	None.

No liming at any time as far as can be ascertained.

(iii) J.E.Burns.

Year	Cropping Programme	Manuring
1933-38	Pasture,	1933 1 cwt. super.

No lime as far as can be ascertained.

(b) Moeraki Type.

(i) E. Smith.

Year	Cropping Programme	Manuring
1933,	Pasture,	-
1934,	"	-
1935,	Oats,	1 cwt. super.
1936,	Wheat,	1 cwt. super.
1937,	Pasture,	-
1938,	"	-

No lime at any time as far as can be ascertained.

(ii) V.O.Frizzell.

Year	Cropping Programme,	Manuring
1933,	Tuscan wheat,	1 cwt. super.
1934,	" "	1 cwt. super.
1935,	Garton oats,	1 cwt. super.
1936,	" "	1 cwt. super.
1937,	Pasture,	1 cwt. super.
1938,	"	-

No lime at any time so far as can be ascertained.

(iii) H. Sail.

Year	Cropping Programme	Manuring
1933,	Pasture,	-
1934,	Wheat,	1 cwt. super.
1935,	Wheat,	1 cwt. super.

Year	Cropping Programme	Manuring
1936,	Pasture,	-
1937,	Pasture,	-
1938,	Pasture,	-

No lime at any time as far as can be ascertained.

(c) Methven, Type 7.

(i) Alec Wilson.

Year	Cropping Programme	Manuring
1933,	Pasture,	-
1934,	Rape,	1 cwt. super.
1935,	Turnip,	1 cwt. super.
1936,	Pasture,	1 cwt. super.
1937,	Pasture,	1 cwt. super.
1938,	Pasture,	-

Lime at 4 cwt. 1936, and 1 cwt. 1937. None previously.

(ii) H.E.Jessep.

Year	Cropping Programme	Manuring
1933,	Pasture,	-
1934,	Pasture,	-
1935,	Turnip,	1 cwt. super.
1936,	Pasture,	1 cwt. super.
1937,	Pasture,	-
1938,	Pasture,	-

No liming as far as can be ascertained.

(iii) Charles Stockdill

Year	Cropping Programme	Manuring
1933 & 1934,	Pasture,	-
1935,	Wheat,	1 cwt. super.
1936,	Wheat,	1 cwt. super.
1937,	Pasture, (sown with wheat, '36),	-
1938,	Pasture,	-

No lime as far as can be ascertained.

(d) Methven, Type 20.

(i) S. Holmes Estate.

Year	Cropping Programme	Manuring
1933 & 1934,	Pasture,	-
1935,	Wheat,	1 cwt. super.
1936,	Oats,	1 cwt. super.
1937,	Pasture (sown with the oats),	-
1938,	Pasture,	-

No lime as far as can be ascertained.

(ii) Andrew Wilson.

Year	Cropping Programme	Manuring
1933-38,	Pasture,	No manure

No lime as far as can be ascertained.

(iii) A.M.Leask.

Year	Cropping Programme	Manuring
1933,	Pasture,	-
1934,	Wheat,	1 cwt. super.
1935,	Wheat,	1 cwt. super.
1936,	Pasture,	1 cwt. super.
1937,	Pasture,	-
1938,	Pasture,	-

(3) The Treatments Applied.

In liming experiments conducted in New Zealand, treatments have been markedly undiversified. Hudson and Montgomery ( ) in their Canterbury investigations use a single treatment of one ton of carbonate, and this is common to the Department of Agriculture's observational trials which were tried out all over the country between the years 1924 and 1929.

This was also considered satisfactory by Dixon (who used these experiments as the basis of his extensive investigations on lime requirement methods. At Mairoa, Dixon,(investigating sheep deficiency diseases from the point of view of lime deficiency, seems satisfied to use farmer's haphazard dressings, varying from 5 cwt. to 2 tons. Mitchell ( ) uses dressings of 1 and 2 tons of burnt lime in his Scottish investigation.

From this it can be seen that results are determined by comparison of relatively few treatments. It does not seem logical that the best results will be obtained over a wide range of soil types from such a small number of treatments, and in this investigation, a complete range of treatments was used. It was at first decided to use Control, ¼ ton, ½ ton, 1 ton, and 2 tons,

but this was later doubled, owing to the very short period of time available in which to obtain results. The final decision was therefore Control, ½ ton, 1 ton, 2 tons, and 4 tons.

(4) The Size, Arrangement and Replication of the Plots.

The dimensions of the plots used by Hudson, Doak and McPherson ( ) in manurial investigations were 26 feet long by 28 inches wide. In the experiments of Hudson and Montgomery ( ) the plots were 22 feet square. Mitchell ( ) adopts a larger plot of 1/36th of an acre.

From a perusal of the evidence gleaned from these papers, it was evident that larger plots, though probably more accurate than smaller plots, involved considerably more labour. Accordingly, it was decided to restrict the dimensions of each plot to 5½ yds. by 5½ yds, (1/160th. acre.) This was considered to be big enough to allow sufficient individual borings without any danger of border effect, and yet still be small enough for one man to establish.

The question of replication was decided only after consideration of the numbers of replicates used by other investigators. In yield trials, Hudson, Doak and Montgomery ( ) ( ) replicate 12 and 18 times. Hudson and Montgomery (in observational trials have only two replicates, and Mitchell(in a somewhat similar investigation to the present one, uses six replicates.

As no yield trials were involved, and the prime function of the investigation was to investigate changes in soil reaction, it was considered that a small number of replicates would be sufficient for accuracy. After also considering the question of treatments and method of arrangement, five was the number of replicates finally decided upon.

After reviewing the methods of arrangement adopted

by the investigators mentioned above, and also making reference to methods of arrangement as presented by Balliere's Encyclopaedia ( ) it was decided to adopt a Latin Square. The Latin Square was considered to be the most suitable type of arrangement for the small number of replicates, and the small number of treatments involved.

Accordingly, a Latin Square was drawn up, containing five replications of the five treatments decided on. The allotment of positions was by a system of controlled random distribution. Treatments were drawn from a hat for each row, but if the resulting position proved unsuitable, it was rejected and drawn again. Positions were considered unsuitable when the replicates fell into any line which would allow a possible fertility gradient to act differentially.

The following standard experiment resulted :

Front

1	2	3	4	5
4	1	0	2	½
½	0	4	1	2
2	½	1	4	0
0	4	2	½	1
1	2	½	0	4

Total area, $\frac{5}{32}$ of an acre.

Plots were pegged out with wooden pegs, and the right angles obtained by using the distances 5 yds, 12 yds., and 13 yds.

(5) Sampling the Plots.

Mitchell ( ) samples to a depth of 9 inches, and Rigg, Kidson and Hodgson ( ) to a depth of six inches, with a few additional 9 - 18 inch samples. While it is considered desirable to sample to a depth of a furrow slice of from 6 to 9 inches, the fact that the length of time available for the action of the lime in the soil was only one year, necessitated a reduction in sampling depth. Therefore, samples were taken to a depth of 4 inches only, as it was considered that changes taking place in the top 4 inches over a period of one year would be indicative of changes in soil reaction over a greater depth in a longer time.

Samples from each plot were taken with a $\frac{5}{8}$ inch auger, and were bored at the rate of nine borings, arranged in three rows, the outer lines being at least three feet in from the edges of the plot, so as to avoid border effects. On the stony soils this did not give a sufficient bulk of sample, and additional borings were made about the centre of the plot. Single plot samplings were taken for the first sampling only. After this, it had been found that little difference occurred between the pH values of the single plots, and the bulked sample,and bulked samples of each treatment were accordingly taken in the second and third samplings.

In bulked samplings, single plots were sampled at the rate of six borings per plot. The borings were well distributed, and all were at least three feet in from the edge of the plot.

All samples were taken to the laboratory in paper bags and there spread out thinly, within 48 hours of boring, for air drying. When air dried, they were rolled with a wooden

roller and passed through a 2 m.m. sieve (International Method), and stored in paper bags for testing. Plots were sampled before the application of the lime (1st sampling), and after the lime had been applied for 8 months (2nd sampling, and for 1 year (3rd sampling). The actual sampling dates are here appended:

TABLE VIII

A Summary of the Sampling Dates of All the Farms Investigated.

Soil Type	Farm	Date of 1st sampling	Date of 2nd	Date of 3rd.
Light land	Ashley Dene, F.W.Lill, J.E.Burns,	28-7-37 29-7-37 26-7-37	15-4-38 15-4-38 16-4-38	17-8-38 17-8-38 19-8-38
Moeraki,	E.Smith, V.O.Frizzell, H.Sail,	12-7-37, 13-7-37 13-7-37	27-4-38 27-4-38 28-4-38	28-8-38 28-8-38 28-8-38
Methven, Type 7.	Alec. Wilson, H.E.Jessep, Charles Stockdill	3-8-37 3-8-37 4-8-37	30-4-38 30-4-38 30-4-38	30-8-38 30-8-38 30-8-38
Methven Type 20	S.Holmes Estate, Andrew Wilson A.M.Leask,	14-7-37 14-7-37 2-8-37	30-4-38 30-4-38 30-4-38	30-8-38* 30-8-38 Plot destroyed

The plots were sampled at the time of pegging out and a small interval occurred before lime applications were made.

(6) The Lime used in the Experiments.

This is dealt with under two headings, (a) The type of lime applied, and (b(The application of the lime.

(a) The Type of Lime Applied.

The lime applied was ordinary commercial ground limestone. The Waikari Lime Company generously donated three tons for the experiment, and this was landed at Lincoln. However,

* This sampling gave imcomprehensible results, and the plot was re-sampled 28-9-38. All data is obtained from this re-sampling.

as only two of the plots were in the vicinity, only a little over ½ a ton was used. Advantage was taken of the Government's free railage scheme by selling the balance of the Waikari lime at Lincoln and using the money to purchase lime from farmers in the other two centres of operations: viz. Cust, and Methven. Thus three separate samples of lime were used, and their analyses appear below: -

TABLE IX

The Analysis of the Three Commercial Limestones used in the Investigation

A. TITRATABLE BASES

Sample A	Sample B	Sample C
75·70%	77·81%	81·33%

B. FINENESS OF GRINDING (Figures in percentages).

	Sample A	Sample B	Sample C
Retained on 10 mesh to the linear inch	·50	1·17	·36
" " 20 mesh and passing 10 mesh,	5·02	9·25	1·88
" " 40 " " " 20 "	10·81	15·54	6·48
" " 60 " " " 40 "	11·85	10·54	10·79
" " 80 " " " 60 "	1·11	2·65	5·18
" " 100 " " " 80 "	21·79	7·19	37·28
Passing through 100 mesh,	48·57	53·66	37·47
Total,	99·65	100·00	99·44

The determination of fineness of grinding was done on 100 gram samples in each case. Sample A represents the limestone from the Waikari words which was used on Ashley Dene and on F.W.Lill's plots. Sample B is also Waikari lime used on all the plots in the Moeraki Soil Type and on J.E.Burns' plot. Sample C was a Timaru limestone used on all of the Methven plots.

(b) The Application of the Lime.

All of the lime was weighed out in a half-kerosene

tin bucket on the College fleece balance, (guaranteed accuracy 1/10th of a lb.) The weights of lime applied to single plots were as follows for the various treatments: -

½ ton, 7 lbs.	2 tons, 28 lbs.
1 ton, 14 lbs.	4 tons, 56 lbs.

The lime was applied by hand in strip with two equal strips for a ½ ton dressing, and four equal ones for a heavier dressing. The outline of the plot was traced out with a thin line of lime and then each strip applied. This enabled the rate of application to be gauged much more finely, and a much more even distribution resulted. Fortunately, very calm weather was experienced during the lime applications, which did not once have to be suspended. During one two light breezes, the lime was applied very close to the ground to avoid drifting onto adjacent plots.

The dates of the lime applications were as follows in Table X.

TABLE X

A Summary of the Dates of the Lime Applications

Soil Type	Farm	Date of application of lime
Light land	Ashley Dene, F. W. Lill, J.E.Burns,	12-8-37 13-8-37 26-8-37
Moeraki,	E. Smith, V. O. Frizzell, H. Sail,	27-8-37 27- 8-37 28- 8-37
Methven, Type 7,	Alec Wilson, H. E. Jessep, Charles Stockdill,	11-8-37 11-8-37 10-8-37
Methven, Type 20,	S. Holmes Estate, Andrew Wilson, A. M. Leask,	4-8-37 10-8-37 12-8-37

(7) The Analysis of the Herbage.

The methods of pasture analysis are ably reviewed

in Agricultural Progress ( ). An account of each method is given by a recognized authority and its limitations discussed. It appears from these accounts that the percentage area method combines accuracy with speed, and gives a true picture of the percentage composition of the sward. The most serious criticism which is levelled against the method is that it gives only an indication as to differences in yield, but as the changes in the percentage composition of the sward are the subject of investigation, this objection carries no weight.

The apparatus used in this method is a grid, 10 inches by 1- inches, which is divided into 100 inch squares by strings stretched across it at inch intervals. The operator casts it down at random and then estimates the percentage area occupied by each species.

The precaution was taken to have a few preliminary casts and estimates, to get an idea of standards to be adopted. At least ten casts were made on each treatment and on areas where the sward was uneven, a larger number of estimates was made.

CHAPTER IV - THE LABORATORY WORK

It is proposed to deal with the laboratory work under the various sections into which the work naturally falls. These are as follows: -

A. The Determination of Lime Requirement.

B. The Determination of Field Responses.

C. The Determination of Volume Weight.

D. The Determination of Organic and Inorganic Colloidal Content.

A. THE DETERMINATION OF LIME REQUIREMENT.

The determination of lime requirement will be dealt with under the following heads: -

(1) The Method Selected, and the Reasons for Selection.

(2) The Application of the Method.

(1) The Method Selected and the Reasons for Selection.

The method selected was Mitchell's ( ) modification of Christensen's ( ) method for determining lime requirements by a method of neutralisation curves.

As previously stated, lime requirement methods have been ably reviewed by Dixon ( ) who considered that no single factor method was satisfactory, and proposed a ratio combining two lime requirement methods. He used the ratio with success in the qualitative determination of lime requirement.

Methods of lime requirement are also ably reviewed in Soil Science ( ). In this article appears a method due to Christensen and Jensen ( ), in which procedure is as follows: different quantities of $\frac{N}{30}$ solution of $Ca(OH)_2$ are shaken with definite weights of air dried soil. After standing for a day, the excess $Ca(OH)_2$ is precipitated off by passing air

or CO_2 through the suspension, and the pH value is then determined by means of Bulman's quinhydrone electrode. Christensen and Jensen found that the amount of lime necessary to bring the soil to a definite pH value in the field was about three times that needed in the laboratory tests.

The method appears to be an advance in several respects on those quoted by Dixon. Firstly, lime requirements can be determined for any pH value to which it is desired to bring the soil, whereas, other methods are limited to determining the lime requirement necessary to bring a given soil to neutrality, or pH 7. That it is a distinct advantage to be able to determine the lime requirement for any pH value is indicated in the section on discussion of results,(p.). Here it is definitely shown that different agricultural crops have different ranges of pH values for optimum growth, and that the best pH value from the point of view of the majority of agricultural crops is slightly on the acid side at approximately pH 6·5 or 6·6.

The second advantage of the method of neutralisation curves is that the relation of laboratory responses with field responses, as indicated by changes in pH values, is determined. This relation is termed the liming factor, and a knowledge of this is important, for it is possible to make an accurate forecast of the amount of lime required by any soil to bring it to any desired pH value, once the liming factor for that soil type has been determined. The basis of this forecast is the determination of the lime requirement by the neutralisation curve method - a rapid and simple procedure. The application of the liming factor transposes the laboratory results to the field.

The method of Christensen and Jensen was slightly modified by Mitchell ( ) who used it successfully in an intensive investigation into the lime status of five Scottish soils. Mitchell used the Hutchinson MacLennan method, the Kappen method, and his own modification of the method of lime requirement by

neutralisation curves due to Christensen and Jensen. He considers that although the ratios of the liming factors were the same, the Hutchinson and MacLennan method accounted for only half, and the Kappen less than half of the lime used. Mitchell points out the advantages cited above, and concludes that the method of neutralisation curves for determining lime requirement is the best method at present available.

Accordingly, this method was chosen for use in this investigation.

(2) The Outline and Standardisation of the Method.

The method used in the determination of lime requirement is as follows: -

In order to prepare the calcium hydroxide solutions carbon-dioxide free distilled water was shaken with pure powdered $Ca(OH)_2$ for about twelve hours and then filtered. After the addition of fresh $Ca(OH)_2$ powder, the filtrate was again shaken for twelve hours. This process was repeated for several days. A concentration of $\frac{N}{20}$ was obtained after a relatively small amount of shaking, but the higher concentration $\frac{N}{10}$ required a much longer period of shaking, and further additions of the solid hydroxide.

Neutralisation curves were then obtained by the addition of different quantities of the $Ca(OH)_2$ solution to 10 gram samples of the air dried soil contained in 100 c.c. flasks. As the pH value was to be determined electrometrically, a constant soil : solution ratio of 1 to 2·5 was maintained by adding, to the different quantities of $\frac{N}{10}$ $Ca(OH)_2$ solution used, sufficient volumes of a solution of 2% sucrose in carbon-dioxide free water. A drop of chloroform was also added to each flask to prevent bacterial fermentation. The flasks were then packed into large tins and shaken on an end over end shaker for twenty-four hours. After removal they were allowed to stand for a

further twenty-four hours before the pH values were determined by means of the quinhydrone electrode.*

In order to standardise the procedure to be used in this investigation, the following initial work was undertaken on one soil type. A twelve point neutralisation curve was obtained by the addition of $\frac{N}{10}$ $Ca(OH)_2$ solution at the rate of 1 c.c., 2 c.c., 3 c.c. etc., up to 12 c.c. to each 10 gram aliquot of soil. The results were compared with a five point curve obtained by the addition of $\frac{N}{10}$ $Ca(OH)_2$ solution at the rate of 2½ c.c., 5 c.c., 7½ c.c., 10 c.c., and 12½ c.c. respectively to 10 gm. samples of the same soil. As the results were in complete agreement, the five point curve is the standard used throughout this work. (See Table Figures Appendix).

The five point curve with similar quantities of $\frac{N}{10}$ $Ca(OH)_2$ solution was then applied both to the twenty-five single plots, making up the five treatments of the first sampling from Alec Wilson's property, and to the bulked samples of the five treatments. Complete agreement was obtained between the curves for the five bulked samples, and those of the single plots, so the five point curve was adopted on bulked samples of each treatment throughout the work.

As the large tins holding the flasks, while being shaken on the end over end shaker, held only twenty-four flasks, one curve in every five was made into a four point curve. This explains the systematic gap which appears in the fourth point for every fifth neutralisation curve determined.

B. THE DETERMINATION OF FIELD RESPONSES.

Field responses were determined, not by herbage yields, but by the changes in pH value induced by the applications

* The determination of pH values is fully described in the next section, (p.)

of lime* pH values were determined electrometrically, using Bulman's quinhydrone electrode.

The saturated calomel electrode was chosen as the standard because it is the most suitable electrode when the apparatus is kept permanently set up, and when determinations of pH values are made at intervals. The apparatus thus consisted of a standard saturated calomel electrode connected with a 35 c.c. cylinder by an agar bridge, prepared with solidified agar and saturated potassium chloride mixture. The glass cylinder was corked with a rubber cork pierced by two holes. Through one hole passed the agar bridge, and through the other a gold electrode. The agar bridge was replaced whenever necessary. The electrode consisted of sheet gold 15 m.m. by 6 m.m. attached to a platinum wire, which was fused into a glass tube. This tube was half filled with a clean mercury contact into which dipped a wire connection. The height of the electrode in the soil suspension was kept constant at a point just above the soil so as to be in contact with the soil particles. The end of the agar bridge was somewhat above this level.

When the electrode became fouled, it was cleaned either by boiling up and cooling in distilled water, or, for more severe cases, boiled in concentrated H_2SO_4, cooled, washed in distilled water and dried in an alcohol flame.

Before commencing the determination of the pH values of any soils, the potentiometer was standardized, and a standard buffer solution was tested. The buffer used was 10·209 grams of acid potassium phthalate, dissolved in a litre of dissolved water. This gave a reading of 229 millivolts at 16°C, equal to a pH value of 3·97. Other millivolt readings for all the water temperatures encountered, were calculated from the formula for the

* A full account of the justification for the assumption that changes in pH values are a true indication of herbage responses, appears on p.

saturated calomel electrode (Wright). A standard soil was also tested. If both the standard buffer solution and the standard soil gave satisfactory readings, then the testing of soil pH values was commenced. If incorrect buffer determinations were made, or the potentiometer needle responded sluggishly, then the connections and electrode were examined for defects.

A test for the pH value of any soil was made by placing in the glass cylinder a 10 gram sample of soil and a pinch of quinhydrone. To this was added 25 c.c. of distilled water* and the whole was shaken together for a few seconds. The electrode and agar bridge were then swiftly inserted and the reading taken. Three readings were taken as quickly as possible, as this was considered to be more accurate than 10 second values. Drifting occurred to a small extent only. It occurred only in the first sampling, and was entirely absent from the soils which had been limed.

C. THE DETERMINATION OF VOLUME WEIGHT.

From time to time various methods have been employed in determining the volume weight of soils. King (proposed the use of a tube of known volume which was driven into the soil, and the removed soil weighed. Warington ( ) gives an account of a similar procedure in which he recommends a tube of not less than six inches diameter, and Stevenson ( ) used the same principle, but constructed a rather elaborate sampler with a battery of cutting teeth which removed a vertical cylindrical section with as little structural disturbance as possible.

Brown, MacIntire and Cree ( ) and Shaw (removed a cube of surface soil and determined its volume weight by displacement of water, after applying an enveloping coat of paraffin. Frosterus and Frouenfelder ( ) obtained results

* This system of 10 gms. and 25 c.c. of distilled water maintains a constant soil : solution ratio of 1 to 2·5, which is the standard for the electrometric determination of pH values.

by the displacement of mercury with the soil sample.

Frear and Erb ( ) adopted a radically different method of attack and measured the volume of the hole from which the sample was taken, using measured volumes of sand for the purpose. Israelson ( ), using the same idea, measured the volume of the hole from which the sample had been taken by inserting a thin walled rubber tube and filling it with measured quantities of water.

None of these methods is entirely satisfactory for all soils. The Israelson method is considered the best for routine determinations, and the Shaw method the best for the study of horizons. However, as no suitable thin walled rubber tube was available, the method of King was resorted to. The tube used was 10 cms. in diameter, falling slightly short of the six inches recommended by Warington.

The method adopted was to take three samples from each farm by driving the tube into the ground to a depth of five inches after clipping off the herbage to ground level. The tube and earth contained was then removed from the soil, and all of the earth contained carefully transferred to suitable tins, which were immediately transported to the laboratory. The soil was then weighed and spread out to air dry. When air dried it was rolled with a wooden roller, and passed through a 2 m.m. sieve, and both the material passing the sieve and the material retained on the sieve were weighed. The material retained on the 2 m.m. sieve consisted of stones and grass roots, and this was discarded after weighing.

The material passing the 2 m.m. sieve was next considered. First the three samples from each farm were considered, and one aliquot from each of approximately 15 gms. weight, was taken. These were accurately weighed out in weighing bottles and placed in an oven at 100°C. for 24 hours and re-weighed. This

weight was the weight of absolutely dry soil, and from this figure was obtained the weight of absolutely dry soil contained in the original sample. The volume of the cylinder was determined both by filling it with water, and by absolute calculation. The volume of the soil was then determined both in grams per c.c. and in lbs. per acre furrow slice of a depth of four inches.

D. THE DETERMINATION OF ORGANIC AND INORGANIC COLLOIDS.

After a consideration of Lyon and Buckman ( ) and Russell ( ), it was decided that the action of soil humus as a buffering agent was so important that it demanded a separate determination of soil organic matter. Accordingly it was decided to determine both the total soil colloids, and the content of organic matter, and these are discussed below under the headings of I and II.

As the group of three farms on each soil type appeared to react similarly, it was decided that one determination of a typical farm on each type was sufficient. However, results on the farm of Chas. Stockdill did not coincide with the other farms on that soil type, and this appeared, from a field examination, to be due to the high content of organic matter which showed itself in the deep black colour of the samples taken from the plots.

Accordingly, total colloids and content of organic matter was determined for five farms, four being typical representatives of the four soil types under investigation, and the fifth, being the farm of Chas. Stockdill, which was the only one showing extraordinary results, when farms were compared with each other on the same type.

I. The Determination of the Inorganic Colloids.

After a review of the methods of determining inorganic colloids, which included pipette methods, methods using

the heat of wetting, and hydrometer methods, it was decided to use a hydrometer method, as this combined speed with accuracy. The method of Bouyoucos ( ), was the one chosen. The apparatus was the same as that described by Bouyoucos, and a quantity of soil equal to 50 gms. + $(100 + \frac{\text{moisture content}}{100})$ was weighed out and placed in the dispersing cup with 75 c.c. of distilled water and 10 c.c. of sodium silicate solution. (Strength of this solution such that hydrometer shows 36 at 67°F). The stirrer was then allowed to run for several seconds to mix up the contents which were then allowed to stand for 20 minutes to complete the shaking.

At the end of that time, the electric stirrer was operated for 10 minutes.* The muddy liquid was then transferred to the hydrometer cylinder, any material on the propellor, corks, or baffles, being transferred by means of a jet of distilled water. When the level reached to several inches below the lower measuring mark on the cylinder, the hydrometer was inserted and the liquid raised by adding distilled water until the meniscus reached the lower mark. The hydrometer was removed and wiped, and the cylinder corked and shaken end over end for sixty seconds.

As the cylinder was set down, the stop-watch was started, and the hydrometer inserted, and readings taken at 40 secs, 2 mins., 3 mins., 4 mins. and 5 mins. The hydrometer was then taken out and wiped and replaced 2 minutes before every subsequent reading, these being taken at 10 mins., 15 mins., 30 mins., 60 mins., and 120 mins.

Suitable additions were made to the reading at the top of the meniscus on the stem of the hydrometer to allow for error due to slight accumulations of froth, and 0·2 of a division was deducted for every 1°F the temperature was below 67°F. (The temperature was taken at regular intervals throughout the experiment.

* 10 minutes was considered the most suitable time, as recommendations were 5 minutes for sands, 8 for sandy loams, and 12 for peats, or very sticky clays.

The readings were taken frequently, in order to take advantage of the equation.*

$$P = \frac{2K}{T^m} = \frac{G}{T^m}$$

where P = percentage in suspension at a time T.

m = the slope of the straight line graph produced by plotting log of hydrometer reading against log of time in minutes.

K = a constant

G and m are constants describing the particular soil, and G is termed the "Fine Material", and "m" the "Settling Rate."

This gives for each soil a definite number obtained from the settling curve.

e.g. $$P = \frac{57.68}{T^{0.066}}$$

These numbers are more easily used in correlating soil properties than the conventional percentages of sand, silt, coarse clay and fine clay, but owing to shortage of time these conventional percentages are the only ones which can be given, and their method of determination is here appended.

Sand = 100 - (2 x hydrom. reading at 40 secs.)

Coarse clay = 2 x (hydrom. reading at 60 minutes - hydrom. reading at 120).

Fine clay = 2 x (hydrom. reading at 120 minutes).

Silt = 100 - (fine clay + coarse clay + sand).

Total = 100%.

II. The Determination of the Organic Matter.

The organic matter content of the soil was determined by the method of loss on ignition. This consisted of heating an oven dry sample to a temperature of 600°C. The figure obtained indicates the organic matter plus a certain amount of combined water held by the soil colloids.

* The equation explained by R.L.James, "Simpler Method of Expressing the Mechanical Analysis of many common soils." Soil Science, Vol. XXXIX, 1935, p. 377 - 389.

PART III

CHAPTER V - THE RESULTS OBTAINED AND THEIR DISCUSSION.

After consideration, it was decided that the results obtained could be most clearly presented and discussed in the following sections:

A. The Results of Determinations of Inorganic and Organic Colloids.

B. The Changes in the pH values in the Field induced by applications of Lime.

C. The Results and Discussion of the Determination of Lime Requirement.

D. The Results and Applications of the Determinations of Volume Weight.

E. The Correlation of the Laboratory Determination of Lime Requirement with Field Response.*

A. RESULTS OF DETERMINATION OF INORGANIC AND ORGANIC COLLOIDS.

These results are summarized in Table XI below:

TABLE XI

(a) Inorganic Colloids by Bouyouces Hydrometer Method.

l Type	Farm	Percentage present of			
		Sand	Fine clay	Coarse Clay	Silt
ght Land	Ashley Dene	38·2	21·8	4·0	36·0
eraki Downs	H. Sail,	23·4	25·4	4·6	46·6
thven 7,	H.E.Jessep,	29·6	34·8	3·4	32·2
thven 20,	Andrew Wilson,	33·0	26·2	4·8	36·0
thven 7,	C.Stockdill,	48·6	18·8	2·8	29·8

(b) Soil Organic Matter by Percentage Loss on Ignition.

Soil Type	Farm	Percentage Loss on Ignition
Light land,	Ashley Dene,	5·1%
Moeraki Downs,	H. Sail,	6·1%
Methven 7,	H.E.Jessep,	5·6%
Methven 20,	Andrew Wilson,	8·1%
Methven 7,	C. Stockdill,	13·8%

* The assumption that changes in pH values are true indications of field response is discussed and justified in this section, results of herbage analysis on the plots being presented in support of this view.

The results of the determinations of inorganic colloids were applied to the chart in Lyon and Buckman ( ) and very close agreement was obtained between the description of the soil type as derived from the mechanical analysis and the description previously given during field examination to each soil type. These results are submitted in Table XII.

TABLE XII.

A Comparison of Soil Name derived from Mechanical Analysis with Name Previously applied.

Soil Type	Description of Soil Type previously given	Description of Type derived from Mechanical Analysis of a Typical Farm.
Light land	Stony silt loam over coarse gravel.	Sandy silt clay loam.
Moeraki	Silty clay loam over heavy clay.	Silty clay loam.
Methven 7.	Stony silt loam and loam.	Sandy silty clay.
Methven 20.	Clay loam and heavy silt loam.	Silty clay loam and sandy loam.

B. THE CHANGES IN THE pH VALUES IN THE FIELD INDUCED BY APPLICATIONS OF LIMESTONE.

The results showing pH changes in the field are appended as follows: -

(I) Tabular results of one typical farm on each soil Type. (Table XIII, p.).

(II) Complete Graphed results which appear in Figure II (p.).

(III) The remaining tabular results of all farms, (except the typical farms appearing in Table XIII) are presented in the Appendix.

Although the results are to a large extent self explanatory, it is proposed to discuss them under two heads: -

I. Errors in Experimental Technique.

II. Differential Lime Responses and their Underlying Causes.

P5

TABLE XIII.

A summary of the pH changes induced by the application of limestone on one typical farm on each Soil Type.

The true changes in pH value due to the application of lime are expressed by a method of subtraction of the control difference, which is due to seasonal change.

e Requirement.

SOIL TYPE. LIGHT LAND.

FARM. F.W. LILL.

First Sampling		Second Sampling at 8 months		Third Sampling at 1 Year.	
c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.
0	5.67	0	5.74	0	5.70
2½	5.97	2½	6.50	1½	5.89
5	6.57	5	7.07	3	6.42
7½	7.08	7½	7.60	4½	6.67
10	7.57	10	7.94	6	---
12½	7.99	12½	8.31	7½	7.43
0	5.64	0	5.82	0	6.01
2½	5.94	2½	6.54	1½	6.17
5	6.67	5	7.17	3	6.58
7½	7.09	7½	7.67	4½	6.86
10	7.50	10	8.02	6	7.22
12½	7.97	12½	8.36	7½	7.47
0	5.36	0	5.86	0	6.01
2½	5.80	2½	6.71	1½	6.22
5	6.52	5	7.23	3	6.52
7½	6.99	7½	7.60	4½	6.86
10	7.53	10	7.99	6	7.16
12½	7.99	12½	8.40	7½	7.45
0	5.64	0	6.05	0	6.13
2½	6.04	2½	6.87	1½	6.42
5	6.60	5	7.32	3	6.65
7½	7.13	7½	7.78	4½	7.02
10	7.60	10	8.06	6	7.29
12½	7.97	12½	8.47	7½	7.54
0	5.15	0	6.14	0	6.31
2½	5.69	2½	7.00	1½	6.79
5	6.38	5	7.40	3	7.01
7½	6.95	7½	7.83	4½	7.20
10	---	10	---	6	7.34
12½	7.80	12½	8.47	7½	7.68

Requirement.

SOIL TYPE. MOERAKI DOWNS.

FARM. E. SMITH.

First Sampling		Second Sampling at 8 months		Third Sampling at 1 Year.	
c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.
0	5.18	0	5.38	0	5.23
2½	5.77	2	6.11	1½	5.73
5	6.47	4	6.73	3	6.56
7½	7.03	6	7.20	4½	6.88
10	7.47	8	7.52	6	----
12½	7.92	10	7.84	7½	7.24
0	5.18	0	5.61	0	5.89
2½	5.84	2	6.39	1½	6.26
5	6.54	4	6.90	3	6.76
7½	7.05	6	7.26	4½	7.06
10	7.61	8	7.67	6	7.32
12½	7.92	10	7.98	7½	7.54
0	5.18	0	5.61	0	6.08
2½	5.84	2	6.39	1½	6.54
5	6.54	4	6.90	3	6.83
7½	7.05	6	7.26	4½	7.13
10	7.61	8	7.67	6	7.34
12½	7.92	10	7.98	7½	7.59
0	5.31	0	5.90	0	6.49
2½	6.05	2	6.44	1½	6.68
5	6.75	4	7.20	3	6.97
7½	7.26	6	7.56	4½	7.20
10	7.71	8	7.93	6	7.47
12½	8.05	10	8.09	7½	7.73
0	5.30	0	5.77	0	6.60
2½	5.96	2	6.76	1½	6.79
5	6.68	4	7.26	3	7.02
7½	7.10	6	7.70	4½	7.25
10	----	8	----	6	7.48
12½	7.94	10	8.04	7½	7.73

Lime Requirement. SOIL TYPE. METHVEN NUMBER 7.

FARM. ALEC. WILSON.

atment	First Sampling		Second Sampling at 8 months.		Third Sampling at 1 Year.	
	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.
	0	5.40	0	5.42	0	5.60
	2½	5.96	2½	6.11	1½	6.05
rol	5	6.60	5	6.73	3	6.37
	7½	7.08	7½	7.16	4½	6.60
	10	7.47	10	7.48	6	----
	12½	7.82	12½	7.85	7½	7.14
	0	5.34	0	5.55	0	5.93
	2½	6.06	2½	6.45	1½	6.14
on	5	6.61	5	6.98	3	6.55
	7½	7.08	7½	7.40	4½	6.82
	10	7.43	10	7.69	6	7.10
	12½	7.79	12½	7.99	7½	7.28
	0	5.36	0	5.59	0	6.09
	2½	6.06	2½	6.55	1½	6.39
on	5	6.61	5	7.05	3	6.62
	7½	7.08	7½	7.49	4½	6.94
	10	7.47	10	7.81	6	7.17
	12½	7.71	12½	8.06	7½	7.53
	0	5.32	0	5.96	0	6.50
	2½	6.10	2½	6.91	1½	6.80
ons	5	6.60	5	7.35	3	7.01
	7½	7.08	7½	7.69	4½	7.30
	10	7.45	10	8.04	6	7.51
	12½	7.82	12½	8.18	7½	7.76
	0	5.31	0	6.19	0	6.75
	2½	6.10	2½	7.16	1½	6.99
ons	5	6.61	5	7.58	3	7.17
	7½	7.06	7½	7.92	4½	7.47
	10	----	10	----	6	7.69
	12½	7.86	12½	8.45	7½	7.94

me Requirement.

SOIL TYPE. METHVEN NUMBER 20.

FARM. ANDY. WILSON.

tment	First Sampling		Second Sampling at 8 months		Third Sampling at 1 Year.	
	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.
ol	0	5.53	0	5.47	0	5.58
	2½	5.64	2½	5.69	1½	5.75
	5	6.07	5	6.37	3	6.14
	7½	6.44	7½	6.76	4½	6.33
	10	6.77	10	6.94	6	----
	12½	7.04	12½	7.26	7½	6.78
	0	5.53	0	5.60	0	5.77
	2½	5.68	2½	6.00	1½	6.08
	5	6.05	5	6.55	3	6.33
	7½	6.42	7½	6.94	4½	6.58
	10	6.70	10	7.14	6	6.82
	12½	7.02	12½	7.44	7½	6.96
	0	5.46	0	5.60	0	5.79
	2½	5.64	2½	6.21	1½	6.15
	5	6.11	5	6.62	3	6.45
	7½	6.44	7½	6.96	4½	6.68
	10	6.72	10	7.21	6	7.00
	12½	7.02	12½	7.47	7½	7.10
s	0	5.50	0	6.04	0	6.30
	2½	5.63	2½	6.57	1½	6.78
	5	6.05	5	6.96	3	6.99
	7½	6.53	7½	7.28	4½	7.19
	10	6.76	10	7.57	6	7.35
	12½	7.00	12½	7.87	7½	7.51
s	0	5.50	0	6.16	0	6.55
	2½	5.79	2½	6.78	1½	6.89
	5	6.11	5	7.12	3	7.06
	7½	6.46	7½	7.31	4½	7.26
	10	----	10	----	6	7.39
	12½	6.98	12½	7.99	7½	7.56

I. Errors in Experimental Technique.

The greatest care was exercised in the determination of the pH values throughout the course of the investigation, and it is proposed that the values obtained are correct ones within narrow bounds of experimental error.

Such seemingly inconsistent results as those presented for the first sampling of F.W.Lill are found to be in order when the results of the pH values of single plots are examined. Plots Number 1 and 2 are extraordinarily acid with pH values of 4·73 and 4·89 respectively. This influence continues as the pH values of these plots at 8 months was 5·95 and 5·86, confirming the previous results, and fully explaining the unusual behaviour of this soil.

The results of the pH determination on control treatments at the three different periods would, at first glance, appear inconsistent. A casual observer would consider that the pH values on unlimed areas should remain the same, and would consider that such wide divergence; as occurs, for instance, between the 1st and 3rd samplings of the control treatment on V.O. Frizzell's or Alec Wilson's plots, (see p); was due to errors in experimental technique.

But this contention can be completely discounted, as the results obtained for control treatments were confirmed by several determinations on different days. Further, it is contended that such changes are quite a normal soil phenomenon. Smith and Robertson ( ) record seasonal changes in pH values of the order of up to 1·0 pH units for uncropped soils. Growing plants reduce the seasonal change which, however, may still be as high as 0·5 of a pH unit.

II. Differential Lime Responses and their Underlying Causes.

A consideration of the graphs of pH changes in the field, shown in Fig II, has indicated that with the exception of

Chas. Stockdill, the farms within each soil type have reacted similarly. The underlying cause of differential changes in pH values, when similar quantities of limestone are added, lies in the different buffer capacity of the various soils under consideration. Buffering is a property of the soil colloids, and a soil which is high in either organic matter or the finer mineral fraction will show a lesser response when measured by the rise in the pH value after applications of limestone, than will a soil low in colloids.

A perusal of the results obtained in colloid analysis presented in Table XI (p.) shows that Stockdill's plot, which has a high content of organic matter, has undergone a small change, and, as previously stated (p.), organic matter must be considered to be the most potent buffering agent in the soil.

With the exception of the Stockdill series, farms on each type reacted very similarly, and it was considered more profitable to discuss the variations in pH values produced from the point of view of types. The highest lime response has been shown by the members of the Moeraki Soil Type, with the Methven soils showing a somewhat smaller change in pH values. The soils of the Light Land Type, however, are remarkable in that changes in pH value have been very small.

The results obtained for the Methven soils and the soils of the Moeraki Type can be readily explained by reference to the figure for inorganic and organic colloids, as the Methven soils show a higher colloid content. The magnitude of the changes in pH value brought about by the heavy applications on the soils of the Light Land series is very small when compared with the changes given by equivalent dressings in the other group. This small change in pH value cannot be explained on the basis of the quantity of organic and inorganic colloids present in these soils, as

the figures for the clay and humus contents are the lowest of all, (Table XI, p.). The reason for the small total pH change can only be a matter of conjecture, and it is suggested that it may be due to a special type of colloid present.

A consideration of the type of reaction as indicated by the slope of the graphs (Fig.II,) proves most interesting. Whereas the curves for the Methven soils, and to a lesser extent the Moeraki soils, indicate a regular rise in pH for larger increments of limestone applied, the curves for the light land soils show a rapid rise in pH for the first 10 cwt. of limestone applied, and a very slow rise in pH values for subsequent increments. This is a point of the utmost practical value, as it indicates that limestone in larger dressings than 10 cwt. is uneconomic on this class of country.

When attention is directed to the responses obtained at 8 months and 12 months,respectively, after the lime applications had been made, it is found that a fairly regular increase in pH value has been exhibited by all soil types, with the exception of Moeraki Downs, which shows a poor response for the first period, and a remarkably good response over the second four monthly period. Such a response is recorded by Mitchell ( ) in his Inschfield soil. Mitchell attributes this to the more highly buffered nature of the Insehfield soil, and this may be the reason for the Moeraki soils, which although not particularly high in clay, contain high percentages of silt.

The absolute changes in pH values have been, on the whole, of small magnitude by comparison with those obtained by Mitchell, and this indicates that all the soils investigated are highly buffered. Mitchell's soils would tend to show less buffering, due to the fact that he used burnt lime.

C. THE RESULTS AND DISCUSSION OF THE DETERMINATION OF LIME REQUIREMENTS

The results of the determinations of lime

requirements are presented for one typical farm on each soil type in Table XVI (p.), and the remainder appear in Tables XVII and XVIII (Appendix). The discussion of the results of lime requirement determinations is presented under two sections, viz.

I. The Accuracy of the Experimental Technique.

II. A Discussion of the Results.

I. The Accuracy of the Experimental Technique.

That the experimental technique has been in the main highly accurate, is evidenced by the similarity between the curves obtained on all plots to which lime had not been added. Also the regular relationships exhibited by all the lime requirement curves in Fig. III (p.), and Figs. IV, V, VI and VII (Appendix, pp.), testify to the accurate nature of the determinations of lime requirement.

However, a slight discrepancy occurs for the farms of F.W.Lill, H.E.Jessep, Andrew Wilson and Charles Stockdill, which appear to be reading slightly high. Other determinations of the pH values in the estimation of lime requirement were made 24 hours after shaking, but owing to disorganization, the pH values for these farms were not determined until three days after shaking: Although chloroform was added to the soil suspensions, it is probable that a certain amount of decomposition of the sucrose buffer had taken place by the end of the three day period, and that this was responsible for the irregular values recorded, or it may have been a dirty electrode.

It is apparent that had the increments of $Ca(OH)_2$ solution been smaller, a lime requirement curve with a maximum pH value in the neighbourhood of the neutral point, would have been obtained. This would give more detailed information over the range of pH values affecting crop growth in acid soils. This fact was realized in the determinations of lime requirement on the 2nd and 3rd samplings, and the increments of $Ca(OH)_2$ solution reduced. However, they could have been profitably reduced still

further.

II. A Discussion of the Results.

As mentioned in Section I above, a survey of Fig. III (p.), and Figs. IV - VII (Appendix pp. gives the relationship of the laboratory determination of Lime Requirement to the results in the field. This is further discussed in the section on "Liming Factors" (p.

After a consideration of the lime requirement determinations on the control treatments, it is evident that the Methven soils are the most highly buffered. The most highly buffered soils are those on the farms of Andrew Wilson and H. E. Jessep, and these are closely followed by the farms of Stockdill and Leask. The soil at Holmes is slightly less buffered, and this is followed by the soil of J.E.Burns, a soil of the light land type. The soils containing the smallest amount of buffer material would appear from these figures to be the other light land farms, Ashley Dene and Lill, and very close to these, are the figures for the Moeraki Downs Soil Type, which show a very even set of values for all farms, indicating relatively slight buffering.

When these results are applied to the pH changes which have occurred in the field, (Fig.II, P.), it can be seen that very close agreement has been obtained for all the soils except those of the light land soil type. The magnitude of the change in pH values in the field is correlated inversely with the buffering capacity of the soil.

In the case of the soils of the light land soil type, the reverse type of correlation occurs. It is significant that the relatively low buffer capacity exhibited by these soils is in agreement with the small colloidal content pointed out in Table XI (p.). From this evidence, it would appear that the small magnitude of the rise in pH value on this class of soil is

not due to the buffering action, but rather to some other cause, such as some factor limiting the solubility of the lime. A study of the changes in pH value which occur during the second year after the application of the lime would be very valuable in providing information on this problem.

D. THE RESULTS AND APPLICATIONS OF THE DETERMINATION OF VOLUME WEIGHT

The results of the volume weight determinations are summarized in Table XVI (p.).

The results are self explanatory, and a careful examination reveals that variations in volume weight are in large measure due to the large amount of stony and gravelly material present in some soils. This failed to pass the 2 m.m. sieve, and was accordingly discarded.

As sampling was in all cases to a depth of 4 inches, and lime requirements were calculated on the basis of the addition of $Ca(OH)_2$ solution to a 10 gm. sample of soil which had passed the 2 m.m. sieve, volume weights were calculated on the basis of the weight of oven dry soil passing the 2 m.m. sieve and contained in an acre furrow slice to a depth of 4 inches. These figures are made use of in the conversion of laboratory additions of $Ca(OH)_2$ solution on each soil type, to tons of commercial ground limestone per acre in each of the graphs in Figs.

These graphs are used in the determination of the "Liming Factors", and without an accurate knowledge of the volume weight, no satisfactory determination of the "Liming Factor" would be possible.

TABLE XVI

Results of Volume Weight Determinations. Average of Three Determinations for each Farm

Soil Type	Farm	Wt, when taken	Air dry material Passing 2 m.m.	Retained by 2 m.m. sieve	% water lost to air dry condition based on wt, of dry soil.	Wt. of aliquot taken	Water loss in wt. after heat, etc.	% of hygroscopic water based on dry soil	Passing gms. per c.c.	Passing 2 m.m. lbs. per acre furrow slic 4" deep.
Light Land	Ashley Dene,	12.92	1015.66	94.66	17.88	15.4842	.2894	1.905	.9993	882.84
Moeraki,	Sail,	1747.66	1259.33	21	37.12	18.1888	.4019	2.259	1.263	115.084
Methven,7,	Jessep	1406	977	109.33	32.71	17.4833	.5697	3.368	.9477	858.84
Methven,20	Andrew Wilson,	1316	710	278.66	46.09	15.7528	.4365	2.849	.6924	627.44
Methven, 7,	Stockdill,	1505	670.5	659	26.17	20.0343	.4910	2.513	.6572	595.44

E. THE CORRELATION OF THE LABORATORY DETERMINATION OF LIME REQUIREMENT WITH FIELD RESPONSE.

It was decided to discuss the correlation of the laboratory determination of lime requirement with field response under two sections, viz.: -

I. The Assumption that Changes in pH value are proportional to Changes in Field Production of Herbage.

II. The Presentation of the "Liming Factors", and a discussion of the Results obtained.

The first section establishes the validity of the relationship between herbage growth and pH values. The second section clarifies the relationship between field and laboratory responses to additions of calcium, and discusses the significance of this relationship.

I. The Assumption that Changes in pH value are proportional to Changes in Field Production of Herbage.

The successful correlation of the laboratory determination of lime requirements with field responses to the application of lime as indicated by changes in pH values,depends on a fundamental assumption.

This assumption is that herbage yields are closely correlated with growth in the field of the plants important to agriculture. It has been supported by numerous investigators. Arrhenius ( ) was one of the earliest investigators on the problem, and after a survey of about 200 farms, he proposed the scale presented in Table XX.

TABLE XX

Soil Reaction and Plant Growth: Survey of about 200 Farms.
Arrhenius (1926)

The unbroken lines indicate frequent occurrence and good yields: the dotted lines poor yields and less common occurrence.

pH	7·5	7	6·5	6	5·5	5	4·5
Alfalfa							
Sugar Beet							
Barley							
Wheat							
Red Clover							
Turnip							
Oats							
Rye							
Swedes							
Timothy							

From the results of Arrhenius, it can be seen that lucerne, sugar beet, barley and red clover do not thrive at all on acid soils, and prefer a reaction about 6·5, swedes, oats, and timothy, however, thrive on acid soils.

These results are confirmed by Russell ( ) who gives a list for English conditions, in which it is recorded that red clover, barley, foxtail, ryegrass, mangolds, sugar beet, peas, beans, and vetches, are less tolerant of acid conditions than are oats, potatoes, swedes and sweet vernal, which may be successfully grown on quite acid soils.

This conception is further supported by Morley Davis ( ) who considers that the pH of the soil is a limiting factor on crop growth, and that the change in pH values required to convert poor stunted growth into healthy vigorous growth is, in many cases, quite small. From a survey of a great number of

crop failures, the approximate points at which the agricultural crops fail is given as : -

Alsyke	5·6
Red Clover	5·5
Sugar Beet, Mangolds, Barley,	5·3
Wheat,	5·1
Swedes, Cabbage and Savoy,	4·9
Kale,	4·5
Ryegrass,	4·3
Oats,	4·2
Potatoes.	4·1

The optimum pH range is unfortunately not stated, but it would be considerably above the point of failure.

Pot experiments by Virtanen and v. Housen ( ) with Finnish species of grasses, indicate that the optimum pH value for Poa pratensis, and for clovers, was 6·5. The pH curve of timothy was very slowly sloping on the acid side, and that of Poa Pratensis very steep. Timothy thus appears much better suited to acid soils - a result in agreement with the findings of other investigators. The pH optimum for cocksfoot, meadow foxtail, and tall fescue is 5·5, and on each side of this point growth becomes weaker. These plants are consequently particularly applicable to acid soils.

The results of the experiments at Rothamsted ( ), where some plots have been made acid by long continued application of sulphate of ammonia, show certain species predominant. These are Bent Grass (Agrostis vulgaris), Sweet Vernal (Anthoxanthum odoratum), narrow-leaved plaintain (Plantago lanceolota), and sorrel (Rumex acetora). After addition of lime had been made to the plots, these species were replaced to a certain extent by foxtail (Alopecurus pratensis), Avena pubescens and Poa pratensis.

Results of herbage analyses carried out on representative farms in the present series are presented in Table XXI. It might be mentioned here that all the pastures analysed were in a "run-out " condition.

TABLE XXI

Results of Herbage Analysis by Percentage Area Method. Percentage analysis average of at least 10 casts for treatment.

Farm, J.E.Burns, representing Soil Type Light Land.

Treatment	Clovers & Trefoil	Bure	Sweet Vernal	Flat Weeds	Hair Grass	Yarrow	Ryegrass.
0	2·8	39·2	53·2	3·5	·8	-	-
½	7·8	22·4	62·7	2·3	3·0	·3	·2
1	9·8	18·3	69·3	2·0	1·3	·4	·9
2	16·3	16·6	58·2	2·7	4·0	1·0	-
4	21·8	11·1	57·8	1·9	2·3	4·3	1·2

Farm, H. Sail, representing Soil Type Moeraki Downs.

Treatment	Flat weeds	Clovers& Trefoil	Bure	Creep. Bent.	Creep. Fog.	Sweet vernal	Hair grass	Rye grass	Sorrel	Moss
0	13·1	5·2	22·0	10·1	13·3	1·8	29·6	·5	1·0	2·1
½	14·1	24·9	14·2	6·0	10·6	-	27·0	·8	·2	·9
1	14·7	35·9	9·6	5·3	17·7	-	15·7	1·9	-	·2
2	11·8	45·5	7·8	8·5	9·0	·5	12·2	3·5	-	·2
4	11·8	51·8	6·0	7·7	9·4	-	7·2	4·7	-	·2

Farm, H.E.Jessep, representing Soil Type Methven Type 7.

Treatment	Bare Ground	Flat weeds	Clovers & Trefoil	Ryegrass	Browntop.
0	44·5	8·7	9·9	34·8	-
½	20·9	7·0	25·0	43·8	1·7
1	19·1	7·0	24·6	51·0	
2	9·2	5·9	36·1	50·8	
4	5·8	6·5	43·3	46·3	

Farm, Andrew Wilson, representing Soil Type Methven Type 20.

Treatment	Clovers & Trefoil	Yarrow	Flat weeds	Bare ground	Moss	Other weeds	Hair grass	Ryegrass	Fog.
0	5·5	2·5	3·7	6·0	3·6	3·2	2·8	2·0	72·3
½	7·0	3·0	3·8	6·7	·7	2·0	7·0	1·9	66·0
1	9·2	2·5	5·2	6·1	1·2	1·6	6·2	2·2	63·6
2	30·6	3·1	9·2	9·8	·2	2·0	5·6	3·2	34·1
4	31·6	2·6	4·2	7·8	2·1	·3	8·4	4·8	34·3

The description of the appearance of the plots at

the time of herbage analysis was as follows: -

J.E.BURNS: Outstanding colour differences shown, Controls yellowish, ½ dead sweet vernal and bare ground, with a very occasional clover plant. As lime dressing increased, plots became darker green in colour, the sweet vernal was greener and closer, and there was very much less bare space, and a marked increase in the clovers, which are chiefly small leaved varieties lying close to the ground, with an occasional red clover plant. Very marked demarcation lines between plots.

H. SAIL: Controls dominated by hair grass, patches of creeping fog and creeping bent: bare ground is much in evidence. The foliage is sparse and yellow. There is a very marked colour change to dark green on the limed plots, and a great thickening of the sward, the clovers being present to almost 100% in some patches. Hair grass particularly, almost totally disappears, and patches of fog and creeping bent are very much smaller in extent.

H.E.JESSEP: The different plots were easily distinguished yards away. The pasture is fairly recent and comparatively good. The controls show yellowing, lack of clovers, and a general lack of denseness in the sward as evidenced by the large amount of bare spaces.

ANDY WILSON: Easily distinguished controls characterized by dried off yellow fog and bare ground, Progressively darker green and much more clovers.

As a general conclusion, it can be stated that the result of the applications of lime was a very marked increase in the clover content, and a reduction in the amounts of the poor grasses, such as Yorkshire Fog, Sweet Vernal and Creeping Bent. Thus investigations have shown changes in the present series of plots to be similar to those previously recorded.

The investigation of H.P.Cooper ( ) is the

Reference
Number 86 Truog, E. 1921. Bull. Wisconsin Agric. Expt. Station. P. 321.

" 87 Virtanen, A.I. and v. Hausen, S. "The Influence of the Acidity of the Soil on the Growth of our Meadow Grasses." Bull. Ylipainos Kirjasta "Suomen Laiduntalous 11" Helsink 1930.

" 88 Wild, L.J. 1917. "Some Soils of the Southern Island of New Zealand with special reference to their lime requirements" J.Agr.Sc. Vol.viii. Mar. 1917. Pt. 11. p. 154 - 178.

" 89 Woodcock, J.W. 1935. "The Use of Lime in New Zealand". Paper to 1935 Grasslands Conference.

" 90 Wright, C. Harold 1931. "Soil Analysis Physical and Chemical Methods" 1931. pp. 56 - 61.

" 91 New Zealand Official Year Book 1938. P. 392.

" 92 Brenchley, W.E. 1924. "Manuring of Grassland for Hay". Rothamsted Monographs.

" 93 Warington, R. "Physical Properties of Soils." pp. 45-55.

only one in an extensive literature in which no correlation is considered to occur between the growth of pasture plants and soil acidity as measured by pH values. Cooper considered that a well balanced supply of available cationic and anionic nutrient material, with relatively high oxidation - reduction potential was much more effective in determing the dominance of pasture plants than the hydrogen ion concentration.

Although Cooper reaches these conclusions, it seems significant that clovers appear only once in his list of species, and it would appear from the great bulk of evidence that the pH value does have a great influence on the plants which can be grown. Apparently, with the exception of cocksfoot and timothy, and possibly subterranean clover, all of the better grasses and clovers are unable to tolerate acid conditions. To obtain the optimum growth of ryegrass, red and white clover, foxtail, poa pratensis, etc., it is necessary to have a soil pH value in the neighbourhood of 6·5. Growth of these good species, diminishes, as acidity increases, at first slightly, and then markedly, until finally between pH values 5·0 and 5·5, an acid association of Agrostis sp., Sweet Vernal, Yorkshire Fog, Sorrel, Spurrey, etc., dominates.

As a general conclusion then, it can be stated that for the agricultural crops there are some acid tolerant species, such as oats, swedes, potatoes and rye but other agricultural crops, especially legumes and barley, grow best at pH values approaching the neutral point. With the exception of potatoes, the acid tolerant crops will grow as well at a pH level of 6·5, and it is this level which is suggested as the most desirable from both a pastoral and an agricultural point of view.

II. The Presentation of the "Liming Factors" and a discussion of the results obtained.

The derivation of the "Liming Factors" is explained in Fig.III (p.), and Figs. IV - VII (Appendix,

THE "LIMING FACTORS"

Values are given at highest convenient figure when the curve of field response fails to reach pH 6.5, and the most reliable and significant values are underlined.

Soil Type	Farm	Time of sampling	pH value	"Liming Factor"
Light Land	Ashley Dene	8 months	Does not reach 6.0	-
		12 months	6.0	-
		12 months	6.2	6.67
Light Land	J.E.Burns,	8 months	Does not reach 6.0	-
		12 months	6.0	6.00
		12 months	6.3	6.11
Light Land	F.W.Lill,	8 months,	6.0	13.50
		12 months,	6.0	1.25
		12 months,	6.3	7.25
Moeraki Downs	H. Sail,	8 months,	Does not reach 6.0	-
		12 months,	6.0	1.17
		12 months,	6.5	2.05
Moeraki Downs	V.O.Frizzell	8 months,	Does not reach 6.0	-
		12 months,	6.0	1.14
		12 months,	6.5	2.64
Moeraki Downs	E. Smith,	8 months,	Does not reach 6.0	-
		12 months,	6.0	1.36
		12 months,	6.5	2.00
Methven, 7,	H.E.Jessep,	8 months	6.0	4.23
		12 months	6.0	2.00
		12 months	6.5	2.69
Methven, 7,	Alec Wilson	8 months,	6.0	4.64
		12 months,	6.0	2.63
		12 months,	6.5	2.40
Methven, 7,	Chas. Stockdill,	8 months,	Does not reach 6.0	-
		12 months,	6.0	7.29
		12 months,	6.1	8.00
Methven, 20,	Andrew Wilson,	8 months,	6. 0	2.80
		12 months,	6.0	4.18
		12 months,	6.5	3.33
Methven, 20	S. Holmes,	8 months,	6.0	8.57
		12 months,	6.0	2.75
		12 months,	6.3	5.71
Methven, 20,	A.M.Leask,	8 months,	5.9	7.4

p.). The most significant values are the factors obtained at the higher pH values on the 12 months sampling.

The Liming Factors obtained by the original investigators using neutralisation curves (Christensen and Jensen (13)) were of the order of 3·0, while Mitchell (67) obtained values varying from 1·5 to 3·0. Mitchell used 2 tons of burnt lime worked into the soil, and his sampling was to a depth of 9 inches. The Liming Factors obtained in this investigation are in the main comparable with those recorded above. The soils on the Light Land Type are marked exceptions with remarkably high factors of the order of 6·5, and so maintain the marked peculiarity which they have exhibited throughout this investigation.

The only other Liming Factor not comparable with the values of other investigators is that of Stockdill, who is abnormally high, and shows the greatest dissimilarity possible from the two farms on the same Soil,Type. This is considered to be due to the very high content of organic matter (Table XI,p.) as organic soils are stated by Lyon and Buckman (59) to be very highly buffered, and to give a relatively small change in pH value for a given addition of lime when compared with mineral soils of similar pH value.

A feature of the Liming Factors is their close similarity within each soil type. This similarity is very marked in the farms within the Light Land and Moeraki Downs soil types, and is exhibited to a lessened degree by the farms on Methven, Type 20. The accuracy of the results of Methven, Type 20, are unfortunately undermined to a certain extent by the loss of one of the plots at a critical stage. It is significant, however, that the result for this plot at 8 months is similar to that obtained for S. Holmes on the same type, and it seems reasonably assured that final results would have been of the same order as Andrew Wilson

and S. Holmes.

The Liming Factors for the farms of H.E.Jessep and Alec. Wilson agree closely, and these must be considered as true representatives of the type Methven 7. The factor for the farm of Stockdill, however, shows the widest divergence possible. This result is in complete agreement with the markedly dissimilar results obtained for this farm throughout the investigation, and the conclusion seems obvious that the farm of Stockdill does not belong to Methven Type 7, but to some other type not specified. This conclusion is supported by the fact that the Soil Survey of the Ashburton County (Grange), on which these soil types are based, is a rapid survey, made for irrigation purposes.

The results obtained for the soil type Methven, 7, indicate how essential it is for this type of investigation, that soil types should be clearly demarcated. If this is not so, no accurate determination of Liming Factors can be made. Still greater errors are incurred when attempts are being made, either to forecast responses from given additions of lime, or to specify given amounts of lime required to produce a given rise in pH values.

The Liming Factors show a very close inverse relationship to the pH values in the field. (Compare Table XXII, p. and Fig.II, p.). Farms showing high liming factors such as the soils of the Light Land Type, and the farm of Charles Stockdill, show very high liming factors of the order of 6·0 - 8·0, while those farms showing a large change in pH values for the application of lime, such as all the farms on the Moeraki Type, have universally low liming factors of approximately 2. Intermediate results showing just as close a correlation are provided by the soils of the Methven Types. Type 7, with lower factors, shows a higher relative change than Type 20, whose factors are somewhat larger.

Chapter VI.

SUMMARY AND CONCLUSIONS

As outlined on P. 36 the aim of the investigation was to correlate the pH changes induced in the field by the application of lime with laboratory determined lime requirements and thus obtain a liming factor which, in conjunction with laboratory determinations alone, could be used in the future as an accurate forecast of field responses obtained from the application of limestone.

An additional aim of the investigation, subordinate to the main objective, was the explanation of any differential lime responses obtained. That these objectives have been substantially realized is demonstrated by the following summary of results.

Summary.

The term soil acidity was defined and its dependence on the parent material, climate and vegetation established for relevent soil groups. A review is made of the influence on the plant of the numerous factors constituting the growth - inhibiting - complex of soil acidity and of the utilization of the compounds of calcium in relieving this condition.

The practice of liming was briefly reviewed historically and evidence of its influence on the soil from the physical, chemical and biological viewpoint presented and analyzed. Previous work on the application of limestone dressings to acid soil as a factor in the growth of crops was discussed, and its effectiveness examined regarding quantities applied, fineness of grinding and purity and mineral characteristics of the stone. The historical development of the use of lime in New Zealand was traced and its utilization reviewed with respect to methods of application and the quality of the material available. All experimental work dealing with lime

this country has been closely examined.

Representative soil types were chosen for the experimental work and a detailed description was given of these soils. Standard technique regarding treatment, size of plots, arrangement and replication was adopted. The limestone used in the experiments was shown to be typical of that commercially available in New Zealand.

Lime Requirements were determined by Mitchell's (67) modification of Christensen and Jensen's (13) method of neutralisation curves. In this method successive increments of Calcium hydroxide solution were shaken with a standard weight of 10 gms. of soil and after twenty-four hours the pH was determined by means of Bulman's quinhydrone electrode.

The increments of Calcium hydroxide solution were converted into tons of Calcium carbonate of 80% purity (average commercial stone) by the use of the results obtained in volume weight determinations on all soil types. Curves in which pH values were plotted against tons of commercial limestone were then constructed, both for results in the field, and for the laboratory determinations of lime requirement, and the relationship between the two was obtained by horizontal intercepts at pH values previously determined as plant growth optimums. The resulting relationship, though varying as between soil types, was proved to be a constant within a single soil type, and was called the "liming factor" for that soil. When the liming factor is known its application to the laboratory determination of lime requirement alone thus gives a figure for the quantity of lime to be applied in the field to reach a desired pH value.

This was the primary objective of the investigation.

Determinations of inorganic colloids and soil organic matter were made and the results successfully applied in the explanation of differential pH changes and "Liming Factors" which were recorded. Success was not obtained,

however in an attempt to correlate the relationship of the soils of the Light Land type on this basis as, although reacting as highly buffered soils, results of colloid determinations placed them in the more lightly buffered class.

Conclusions.

As stated above the primary objects of the investigation have been successfully realized, satisfactory "liming factors" being obtained on soils which reached a pH value in the field of 6.5 after lime had been applied for twelve months. Thus one of the determinations on which the "liming factor" is based is the reaction of the soil following twelve months application of lime as the carbonate. Under such circumstances the figures obtained may not represent the true values as in many instances a more intensified reaction occurs during the second year after lime application and as a result the pH in the field rises reducing the value of the "liming factor". However it is considered that this change, if any, will be small in nature and that the "liming factors" determined in this investigation can therefore be freely used as a basis of an advisory service on the four Soil Types investigated. Prediction of the results of lime responses under this system has prospects of being 100% accurate.

The minor aim of the investigation was to correlate differential lime responses with the buffering capacity of the soil as expressed by the content of soil colloids evidenced by determinations of inorganic colloids and soil organic matter. Very close correlations were obtained on all soils with the exception of those of the Light Land Soil Type. The soils of this type all reacted similarly in a manner which could not be correlated with their colloid content and the reason for this differential response must remain a matter of conjecture.

This anomalous behaviour exhibited by the Light

Land Soil Type is encountered again when a study is made of the shape of the curve, produced by plotting pH values obtained in the field against lime applications. Whereas, all the other soils investigated show a gradual rise in pH value due to increasing increments of added limestone, the soils of the Light Land Soil Type show a marked rise in pH for the application of a dressing of 10 cwt., but a very much reduced rise in pH values for any succeeding increments even up to the high figure of 4 tons per acre. Dressings greater than 10 cwt. are consequently of little value. The results obtained show very definitely that this is the case and are consequently of the greatest practical value in making recommendations on this type.

All the farms within each soil type gave reactions similar in nature in every avenue investigated, with the exception of Charles Stockdill's farm which consistently gave results diverging very widely from the other farms on the soil type. The results obtained for the other two farms were in every case very closely related. The obvious conclusion is that the farm of Stockdill belongs to a different type of soil from the other two members of Methven 7. This is supported by the fact that "liming factors" for Stockdill are three times as large as for the other members of the "type".

A very obvious deduction of the utmost importance can be made from these results. If, in any soil investigation, it is desired to obtain results which can be used as a basis of accurate recommendations and the precise forecasting of responses in the future, then the Soil Type on which the investigation is being carried out must be uniform in nature and clearly demarcated in outline.

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APPENDIX I.

Table xxiii.

Summary of results, (farm of Alec. Wilson (first sampling), proving lime requirements to be similar on both single plots and Bulked Samples of the same treatment.

Treatment - Control.

Plot No. 3		Plot No.7		Plot No.15		Plot No.16		Plot No.24		Bulked Sample	
cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values
0	5.29	0	5.32	0	5.31	0	5.34	0	5.37	0	5.40
2½	5.90	2½	5.97	2½	5.95	2½	6.00	2½	6.03	2½	5.96
5	6.57	5	6.64	5	6.53	5	6.56	5	6.54	5	6.60
7½	7.10	7½	7.06	7½	7.04	7½	7.06	7½	7.06	7½	7.08
10	7.53	10	7.55	10	—	10	7.47	10	7.44	10	7.47
12½	7.89	12½	7.90	12½	7.91	12½	7.84	12½	7.82	12½	7.82

Treatment ½ ton.

Plot No. 5		Plot No. 6		Plot No.12		Plot No.19		Plot No.23		Bulked Sample	
cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values
0	5.25	0	5.34	0	5.32	0	5.37	0	5.31	0	5.34
2½	6.09	2½	5.97	2½	6.95	2½	6.00	2½	6.11	2½	6.06
5	6.64	5	6.55	5	6.67	5	6.56	5	6.68	5	6.61
7½	7.17	7½	7.01	7½	7.05	7½	7.06	7½	7.09	7½	7.08
10	—	10	7.41	10	7.44	10	7.47	10	7.51	10	7.43
12½	7.81	12½	7.80	12½	7.80	12½	7.84	12½	7.84	12½	7.79

APPENDIX II.

Table xxiii. Continued.

Treatment 1 ton.

Plot No. 2		Plot No. 9		Plot No.13		Plot No.20		Plot No.21		Bulked Sample	
cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values
0	5.29	0	5.24	0	5.17	0	5.25	0	5.31	0	5.36
2½	6.08	2½	5.92	2½	5.86	2½	5.99	2½	5.91	2½	6.06
5	6.56	5	6.29	5	6.34	5	6.48	5	6.56	5	6.61
7½	7.07	7½	6.89	7½	6.89	7½	6.90	7½	7.02	7½	7.08
10	7.49	10	1.29	10	7.27	10	--	10	7.37	10	7.47
12½	7.81	12½	7.65	12½	7.66	12½	7.70	12½	7.87	12½	7.71

Treatment 2 tons.

Plot No. 4		Plot No.10		Plot No.11		Plot No. 18		Plot No.22		Bulked Sample	
cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH values	cc N/10 $Ca(OH)_2$	pH values.
0	5.29	0	5.22	0	5.34	0	5.37	0	5.37	0	5.32
2½	6.01	2½	6.01	2½	5.88	2½	5.95	2½	6.05	2½	6.10
5	6.56	5	6.38	5	6.55	5	6.60	5	6.60	5	6.60
7½	7.07	7½	6.91	7½	6.89	7½	6.99	7½	7.06	7½	7.08
10	7.42	10	7.72	10	7.34	10	7.40	10	7.46	10	7.45
12½	7.76	12½	--	12½	7.71	12½	7.77	12½	7.87	12½	7.82

Treatment 4 tons

Plot No. 1		Plot No. 8		Plot No.14		Plot No.17		Plot No.25		Bulked Sample	
cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH values	cc N/10 $Ca(OH)_2$	pH Values	cc N/10 $Ca(OH)_2$	pH Values
0	5.39	0	5.34	0	5.27	0	5.43	0	5.31	0	5.31
2½	5.92	2½	5.96	2½	5.90	2½	6.04	2½	5.94	2½	6.10
5	6.59	5	6.36	5	6.39	5	6.62	5	6.51	5	6.61
7½	7.08	7½	6.91	7½	6.89	7½	7.06	7½	7.00	7½	7.06
10	7.42	10	7.29	10	7.31	10	7.43	10	--	10	--
12½	7.81	12½	7.67	12½	7.64	12½	7.82	12½	7.74	12½	7.86

TABLE XIV.

Summary of the pH changes induced by the addition of commercial ground limestone on two farms of each of the Soil Types, Light land and Moeraki Downs.

The true changes due to the applications of lime are expressed by a method of subtraction of the control difference which is due to seasonal changes.

Lime Requirement.

SOIL TYPE. LIGHT LAND.

FARM. J.E. BURNS.

tment.	First Sampling		Second Sampling at 8 months		Third Sampling at 1 Year.	
	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.
	0	5.55	0	5.60	0	5.51
	2½	5.79	2	5.94	1½	5.92
ol	5	6.35	4	6.51	3	6.35
	7½	6.88	6	6.88	4½	6.64
	10	7.25	8	7.18	6	----
	12½	7.62	10	7.48	7½	7.08
	0	5.50	0	5.54	0	5.70
	2½	5.88	2	6.15	1½	6.12
	5	6.40	4	6.61	3	6.51
	7½	6.84	6	6.93	4½	6.73
	10	7.18	8	7.25	6	7.01
	12½	7.56	10	7.55	7½	7.19
	0	5.48	0	5.72	0	5.84
	2½	5.88	2	6.33	1½	6.23
	5	6.39	4	6.72	3	6.53
	7½	6.86	6	7.02	4½	6.80
	10	7.21	8	7.31	6	7.05
	12½	7.62	10	7.61	7½	7.26
	0	5.54	0	5.92	0	5.94
	2½	5.88	2	6.52	1½	6.41
s	5	6.44	4	6.86	3	6.73
	7½	6.82	6	7.16	4½	6.98
	10	7.21	8	7.43	6	7.19
	12½	7.60	10	7.71	7½	7.37
	0	5.46	0	6.09	0	6.20
	2½	5.84	2	6.65	1½	6.96
s	5	6.35	4	6.92	3	7.14
	7½	6.77	6	7.18	4½	7.33
	10	----	8	----	6	7.44
	12½	7.55	10	7.77	7½	7.62

Lime Requirement. SOIL TYPE. LIGHT LAND.

FARM. ASHLEY DENE.

...ment	First Sampling		Second Sampling at 8 months		Third Sampling at 1 Year.	
	C.C. of N/10 $Ca(OH)_2$.	pH.	C.C. of N/10 $Ca(OH)_2$.	pH.	C.C. of N/10 $Ca(OH)_2$	pH.
	0	5.58	0	5.43	0	5.59
	2½	6.00	2	5.94	1½	5.81
	5	6.69	4	6.68	3	6.31
...rol	7½	7.17	6	7.09	4½	6.63
	10	7.57	8	7.45	6	---
	12½	8.00 x	10	7.82	7½	7.11
	0	5.64	0	5.69	0	5.87
	2½	6.11	2	6.33	1½	6.08
	5	6.71	4	6.84	3	6.44
...	7½	7.08	6	7.18	4½	6.72
	10	7.55	8	7.54	6	6.97
	12½	8.00	10	7.89	7½	7.18
	0	5.58	0	5.71	0	5.84
	2½	6.07	2	6.42	1½	6.22
	5	6.71	4	6.93	3	6.61
...	7½	7.12	6	7.27	4½	6.79
	10	7.61	8	7.63	6	7.08
	12½	7.94	10	7.98	7½	7.25
	0	5.60	0	5.76	0	6.02
	2½	6.13	2	6.60	1½	6.44
	5	6.69	4	7.04	3	6.76
...ns	7½	7.13	6	7.32	4½	6.92
	10	7.57	8	7.70	6	7.13
	12½	7.93	10	8.05	7½	7.32
	0	5.57	0	5.81	0	6.20
	2½	6.09	2	6.86	1½	6.58
	5	6.73	4	7.15	3	6.84
...ns	7½	7.19	6	7.45	4½	7.04
	10	---	8	---	6	7.18
	12½	7.98	10	8.12	7½	7.41

x The upper range of the quinhydrone electrode is discussed by Clark ( ) who places it tentatively at 8.5. Britton ( ) points out that in the presence of buffering agents a pH of up to 8 can be considered accurate. Consequently results above 8.0 are presented as indicative of trends only.

Lime Requirement.

SOIL TYPE. MOERAKI DOWNS.

FARM. V.O. FRIZZELL.

Treatment.	First Sampling		Second Sampling at 8 months		Third Sampling at 1 Year.	
	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.
	0	5.27	0	5.42	0	5.60
	2½	5.56	2	5.96	1½	5.92
ntrol	5	6.42	4	6.71	3	6.46
	7½	6.96	6	7.17	4½	6.78
	10	7.45	8	7.62	6	----
	12½	7.87	10	8.01	7½	7.37
	0	5.29	0	5.55	0	5.99
	2½	5.68	2	6.35	1½	6.23
ton	5	6.35	4	6.92	3	6.67
	7½	6.91	6	7.39	4½	6.92
	10	7.39	8	7.83	6	7.21
	12½	7.87	10	8.08	7½	7.55
	0	5.18	0	5.69	0	6.10
	2½	5.66	2	6.42	1½	6.42
ton	5	6.43	4	7.01	3	6.76
	7½	6.91	6	7.42	4½	7.08
	10	7.41	8	7.85	6	7.33
	12½	7.85	10	8.12	7½	7.64
	0	5.27	0	6.76	0	6.44
	2½	5.58	2	6.65	1½	6.76
tons	5	6.43	4	7.12	3	7.06
	7½	6.89	6	7.60	4½	7.31
	10	7.41	8	8.01	6	7.60
	12½	7.87	10	8.19	7½	7.90
	0	5.17	0	5.78	0	6.86
	2½	5.73	2	6.82	1½	7.19
tons	5	6.38	4	7.21	3	7.39
	7½	6.94	6	7.64	4½	7.64
	10	----	8	----	6	7.92
	12½	7.87	10	8.22	7½	8.17

TABLE XV.

Summary of the pH changes induced by the addition of commercial ground limestone on two farms of each of the Soil Types, Methven 7 and Methven 20.

The true changes due to the applications of lime are expressed by a method of subtraction of the control difference which is due to seasonal changes.

Lime Requirement.

SOIL TYPE. MOERAKI DOWNS.

FARM. FORMERLY H. SAIL.

Treatment	First Sampling		Second Sampling at 8 months		Third Sampling at 1 Year.	
	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.
	0	5.20	0	5.43	0	5.46
	2½	5.58	2	5.89	1½	5.76
	5	6.36	4	6.54	3	6.24
trol	7½	7.02	6	7.04	4½	6.71
	10	7.49	8	7.43	6	----
	12½	8.03	10	7.82	7½	7.25
	0	5.17	0	5.62	0	5.97
	2½	5.60	2	6.28	1½	6.23
	5	6.36	4	6.81	3	6.67
ton	7½	6.98	6	7.25	4½	6.99
	10	7.55	8	7.63	6	7.30
	12½	7.83	10	8.05	7½	7.60
	0	5.10	0	5.47	0	6.04
	2½	5.55	2	6.29	1½	6.42
	5	6.27	4	6.83	3	6.82
ton	7½	6.80	6	7.25	4½	7.12
	10	7.23	8	7.63	6	7.42
	12½	7.94	10	8.09	7½	7.72
	0	5.20	0	5.72	0	6.41
	2½	5.49	2	6.49	1½	6.76
	5	6.33	4	6.93	3	7.08
tons	7½	6.78	6	7.36	4½	7.35
	10	7.17	8	7.64	6	7.62
	12½	7.67	10	8.05	7½	7.94
	0	5.16	0	5.79	0	6.60
	2½	5.55	2	6.66	1½	7.06
	5	6.24	4	7.16	3	7.30
tons	7½	6.82	6	7.55	4½	7.51
	10	----	8	----	6	7.83
	12½	7.65	10	8.19	7½	8.01

Lime Requirement. SOIL TYPE. METHVEN NUMBER 7.

FARM. H.E. JESSEP.

eatment	First Sampling		Second Sampling at 8 months		Third Sampling at 1 Year.	
	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.
	0	5.35	0	5.35	0	5.42
	2½	5.48	2½	5.65	1½	5.71
trol	5	6.04	5	6.40	3	6.08
	7½	6.45	7½	6.75	4½	6.33
	10	6.83	10	7.05	6	----
	12½	7.19	12½	7.33	7½	6.78
	0	5.37	0	5.53	0	5.70
	2½	5.58	2½	6.15	1½	6.00
on	5	6.16	5	6.61	3	6.30
	7½	6.52	7½	6.94	4½	6.53
	10	6.85	10	7.30	6	6.76
	12½	7.16	12½	7.56	7½	6.94
	0	5.32	0	5.53	0	5.93
	2½	5.58	2½	6.20	1½	6.26
on	5	6.18	5	6.70	3	6.53
	7½	6.52	7½	7.00	4½	6.73
	10	6.87	10	7.39	6	6.90
	12½	7.27	12½	7.60	7½	7.12
	0	5.36	0	5.75	0	6.18
	2½	5.55	2½	6.47	1½	6.48
ons	5	6.08	5	6.91	3	6.73
	7½	6.57	7½	7.12	4½	6.94
	10	6.90	10	7.48	6	7.12
	12½	7.20	12½	7.78	7½	7.30
	0	5.40	0	6.04	0	6.66
	2½	5.64	2½	6.84	1½	6.83
ons	5	6.16	5	7.09	3	6.98
	7½	6.57	7½	7.37	4½	7.15
	10	----	10	----	6	7.33
	12½	7.24	12½	8.01	7½	7.53

Lime Requirement. SOIL TYPE. METHVEN NUMBER 7.

FARM. CHARLES STOCKDILL.

Treatment	First Sampling		Second Sampling at 8 months		Third Sampling at 1 Year.	
	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.
	0	5.27	0	5.31	0	5.32
	2½	5.47	2½	5.87	1½	5.67
ntrol	5	6.19	5	6.38	3	6.10
	7½	6.65	7½	6.81	4½	6.32
	10	7.04	10	7.15	6	----
	12½	7.37	12½	7.45	7½	6.76
	0	5.29	0	5.48	0	5.65
	2½	5.56	2½	6.13	1½	6.05
ton	5	6.17	5	6.52	3	6.33
	7½	6.69	7½	6.93	4½	6.51
	10	7.00	10	7.25	6	6.69
	12½	7.34	12½	7.55	7½	6.87
	0	5.38	0	5.54	0	5.83
	2½	5.65	2½	6.21	1½	6.12
ton	5	6.29	5	6.61	3	6.44
	7½	6.70	7½	7.00	4½	6.60
	10	7.02	10	7.32	6	6.80
	12½	7.37	12½	7.57	7½	6.98
	0	5.30	0	5.61	0	5.90
	2½	5.67	2½	6.42	1½	6.41
tons	5	6.28	5	6.70	3	6.62
	7½	6.65	7½	7.08	4½	6.76
	10	7.04	10	7.34	6	6.89
	12½	7.37	12½	7.66	7½	7.03
	0	5.27	0	5.83	0	6.10
	2½	5.68	2½	6.83	1½	6.76
tons	5	6.28	5	6.97	3	6.90
	7½	6.51	7½	7.15	4½	7.01
	10	----	10	----	6	7.28
	12½	7.34	12½	7.77	7½	7.51

Lime Requirement.

SOIL TYPE. METHVEN TYPE 20.

FARM. S. HOLMES ESTATE.

Treatment	First Sampling		Second Sampling at 8 months		Third Sampling at 1 Year.	
	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.
	0	5.36	0	5.29	0	5.28
	2½	5.71	2½	5.89	1½	5.58
ntrol	5	6.38	5	6.58	3	5.94
	7½	6.93	7½	7.01	4½	6.38
	10	7.18	10	7.37	6	-
	12½	7.46	12½	7.74	7½	6.98
	0	5.36	0	5.57	0	5.63
	2½	5.73	2½	6.19	1½	5.92
on	5	6.31	5	6.71	3	6.30
	7½	6.80	7½	7.15	4½	6.69
	10	7.11	10	7.53	6	7.02
	12½	7.39	12½	7.87	7½	7.34
	0	5.35	0	5.73	0	5.92
	2½	5.73	2½	6.28	1½	6.24
on	5	6.36	5	6.82	3	6.58
	7½	6.81	7½	7.24	4½	6.90
	10	7.11	10	7.60	6	7.30
	12½	7.48	12½	7.96	7½	7.58
	0	5.38	0	5.89	0	6.06
	2½	5.85	2½	6.53	1½	6.38
tons	5	6.49	5	6.98	3	6.72
	7½	6.80	7½	7.42	4½	7.12
	10	7.15	10	7.78	6	7.49
	12½	7.48	12½	8.08	7½	7.75
	0	5.43	0	5.99	0	6.31
	2½	5.69	2½	6.80	1½	6.63
tons	5	6.22	5	7.17	3	6.95
	7½	6.74	7½	7.58	4½	7.36
	10	----	10	----	6	7.62
	12½	7.45	12½	8.15	7½	7.86

Lime Requirement.

SOIL TYPE. METHVEN NUMBER 20.

FARM. A.M. LEASK.

eatment	First Sampling		Second Sampling at 8 months		Third Sampling at 1 Year.
	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.	pH.	c.c. of N/10 $Ca(OH)_2$.
	0	5.34	0	5.40	
	2½	5.64	2½	5.87	Position of plot lost through trampling by horses and cutting off pegs by mower.
trol	5	6.18	5	6.47	
	7½	6.59	7½	6.81	
	10	6.97	10	7.11	
	12½	7.32	12½	7.48	
	0	5.39	0	5.61	
	2½	5.76	2½	6.17	
on	5	6.24	5	6.60	
	7½	6.60	7½	6.90	
	10	6.90	10	7.27	
	12½	7.31	12½	7.57	
	0	5.48	0	5.68	
	2½	5.71	2½	6.30	
on	5	6.29	5	6.74	
	7½	6.66	7½	7.04	
	10	6.94	10	7.38	
	12½	7.27	12½	7.70	
	0	5.41	0	5.78	
	2½	5.80	2½	6.45	
ons	5	6.22	5	6.90	
	7½	6.66	7½	7.16	
	10	6.97	10	7.43	
	12½	7.27	12½	7.76	
	0	5.48	0	5.92	
	2½	5.83	2½	6.74	
ons	5	6.25	5	7.04	
	7½	6.67	7½	7.31	
	10	----	10	----	
	12½	7.29	12½	7.93	

Graphs of one typical farm on each Soil Type after lime had been applied for one year.

Curves are obtained by plotting pH values against calcium, expressed as tons of commercial ground limestone.

Curves are shown as:-

Laboratory Additions of $Ca(OH)_2$

Field Additions of Commercial Ground Limestone

Farm and Soil Types are as follows:-

Soil Type	Farm
Light Land	F.W. Lill
Moeraki	H. Sail
Methven Type 7	H.E. Jessep
Methven Type 20	Andrew Wilson

Lime Requirement Factors are obtained by -

$$\frac{\text{Length of Horizontal Intercept of Field Curve.}}{\text{Length of Horizontal Intercept of Curve of Laboratory Addition of } Ca(OH)_2 \text{ Solution.}}$$

at pH values of 6.0 and 6.5 with the highest convenient value of field curve where this does not reach 6.5

Graphs of the Soil Type LIGHT LAND which includes the farms of Ashley Dene and J.E. Burns sampled at 8 months and 12 months, after lime had been applied, and F.W.Lill at 8 months. The curves are obtained by plotting pH values against the additions of calcium, expressed as tons of commercial ground-limestone.

The curves consist of :-

Laboratory additions of $Ca(OH)_2$ solution.

Field additions of commercial ground-lime-stone.

Lime requirement factors are obtained by :-

$$\frac{\text{Length of horizontal intercept of field curve.}}{\text{Length of horizontal intercept of laboratory curve, (control curve)}}$$

At the pH values of 6.0 and 6.5 except where the field curve does not reach the value of 6.5 in which case the highest convenient value is taken.

Graphs of the Soil Type MOERAKI DOWNS which includes the farms of V.O. Frizzell and E. Smith sampled at 8 months and 12 months, after lime had been applied, and H. Sail at 8 months. The curves are obtained by plotting pH values against the additions of calcium, expressed as tons of commercial ground-lime-stone.

The curves consist of :-

Laboratory additions of $Ca(OH)_2$ solution.

Field additions of commercial ground-lime-stone.

Lime requirement factors are obtained by :-

$$\frac{\text{Length of horizontal intercept of field curve.}}{\text{Length of horizontal intercept of laboratory curve, (control curve)}}$$

At the pH values of 6.0 and 6.5 except where the field curve does not reach the value of 6.5 in which case the highest convenient value is taken.

Graphs of the Soil Type METHVEN TYPE 7 which includes the farms of Alec. Wilson and Chas Stockdill, sampled at 8 months and 12 months, and H.E. Jessop at 8 months. The curves are obtained by plotting pH values against the additions of calcium, expressed as tons of commercial ground-lime stone.

The curves consist of :-

Laboratory additions of Ca $(OH)_2$ solution.

Field additions of commercial ground-lime stone.

Lime requirement factors are obtained by :-

Length of horizontal intercept of field curve.

Length of horizontal intercept of laboratory curve, (control curve)

At the pH values of 6.0 and 6.5 except where the field curve does not reach the value of 6.5 in which case the highest convenient value is taken.

Graphs of the Soil Type METHVEN TYPE 20 which includes the farm of S. Holmes Estate, sampled at 8 months and 12 months, after lime had been applied, and the farms of A.M. Leask and Andrew Wilson at 8 months. The curves are obtained by plotting pH values against the additions of calcium, expressed as tons of commercial ground-limestone.

The curves consist of :-

Laboratory additions of $Ca(OH)_2$ solution.

Field additions of commercial ground-limestone.

Lime requirement factors are obtained by :-

$$\frac{\text{Length of horizontal intercept of field curve.}}{\text{Length of horizontal intercept of laboratory curve, (control curve)}}$$

At the pH values of 6.0 and 6.5 except where the field curve does not reach the value of 6.5 in which case the highest convenient value is taken.

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