T H E S I S.

Submitted for M. Agr. Sc. Degree.

"A STUDY OF THE YIELDS OF VARIOUS SPECIES OF PASTURE PLANTS, AND SOME OF THEIR STRAINS, WHEN GROWING IN A SOIL BROUGHT TO VARIOUS LEVELS OF HYDROGEN-ION CONCENTRATION."

by

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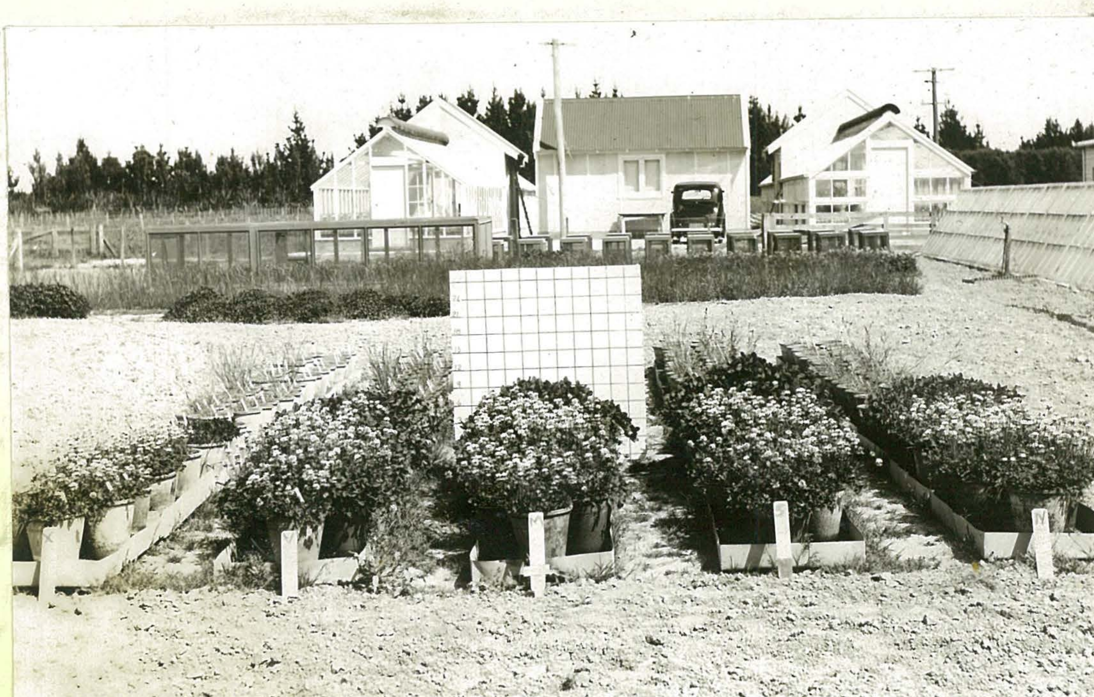

Photo. 18th Dec. 1946.

This shows a general view of the experimental area. The most acid treatment is at the extreme left and the neutral treatment on the right. White clovers are in the foreground, Montgomery red clover shows black just behind, while the grass series are further back still.

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INTRODUCTION.

1. General.

During the past few decades, our country, along with other important primary producers, has come to realise with increasing force the real importance of pasture production to mankind. In New Zealand over nine tenths of the value of our exports comes directly or indirectly from grasslands. This realisation has been reflected in the marked extension in research, not only towards the improvement of pasture species and strains, but also in an attempt to learn more of the conditions in the soil that are most ideal for maximum production.

As a plant can produce only as much as its inherent potential and its external environment will allow, it becomes all workers to consider both sides of the question of maximum production. As a result of work done by the Grasslands Division of the Plant Research Bureau since its inception, strains of new pasture species have been developed which will produce very highly under conditions favourable to their growth. Thus if these strains are used in agriculture and maximum production is not obtained, managemental and environmental factors must be the limiting ones. Of the environmental factors, five claim pride of place where pasture production is concerned:-

(a) Soil moisture
(b) Soil and air temperature
(c) Light intensity
(d) Soil fertility
(e) Soil acidity

In practice the first three factors are mainly dependent on climatic conditions, though by suitably controlled irrigation and drainage both soil moisture and soil temperature can be influenced and plant growth markedly increased.

The problem of light intensity needs research in this country, but it is known that some species, such as Prairie grass (Bromus catharticus) and Cocksfoot (Dactylis glomerata) thrive when a certain amount of shade is provided for their crown, while others such as Indian doub (Cynodon dactylon) or English hair-grass (Aira caryaphyllia) grow best under open sunny conditions. Thus although climate can play an important part in this factor, it is obvious that, as Nilsson-Leissner has said ".....if we know the special requirements of a certain strain or group of strains of pasture plants we can adapt our system of grazing management and of manuring and so on, in such a way that we favour or hamper that particular group....."

Soil fertility as usually considered includes all other factors of soil environment but here the term is used to mean the ability of the soil to supply the growing plant with all the nutrient requirements normally absorbed through the root system. It is well known that this is usually the most important factor limiting plant growth, but much can be done by manurial applications to counteract any deficiencies that may be limiting plant growth.

The fifth factor of soil acidity or Hydrogen-ion concentration is partially wrapped up in its effects with fertility, because it is known for instance that under acid conditions some nutrients - particularly calcium and magnesium are usually leached out while under alkaline conditions others like Potassium and iron may be held in forms unavailable to the plants. (Pettinger, 1935.) However apart from this indirect effect, the Hydrogen-ion seems to have a direct bearing on the growth of a plant, even when special measures have been taken to make all nutrients available. (Lundegardh, 1931).

Thus it would seem that the soil acidity, or soil reaction as it is often called, when combined with the resultant degree of nutrient availability, plays a very important part in regulating plant growth.

Soil acidity depends on the Hydrogen-ion concentration in the soil and this is usually measured and expressed as the pH value for that soil. The pH may be defined as "the negative index of ten which expresses the concentration of Hydrogen-ion in the solution of the acid". (Russell 1927.) A pH of 7 represents a neutral solution with equal amounts of Hydrogen-ions and Hydroxyl-ions, while a smaller number, e.g. pH 3 is more acid and pH 9 more alkaline. The natural pH of soils in New Zealand varies considerably from 4.1 to 8.1. (Annual Report D.S.& I.R.) but the more usual range in agricultural soils is between 5 and 7. (Lyon & Buckman 1943). It is of interest that the extremes of acidity recorded in the world are pH 1.7 in America on the acid side (Arrherius 1922), and pH 11 in Egypt, on the alkaline side (Lundegardh, 1931.)

2. Object of Present Work.

It is usually recognised that different plants thrive best at different levels of soil acidity, e.g. potatoes best at pH 4.8 to 5.4, asparagus at 6.0 to 6.7 etc. (Work, 1945), so the present work was undertaken in an attempt to throw light on the following points:-

(a) Is there one level of soil acidity optimum to all of the following species of pasture plants, and if not what level suits each species?

Perennial ryegrass	Lolium perenne
Italian ryegrass	Lolium multiflorum
Short Rotation ryegrass	L. perenne, L. multiflorum
Cocksfoot	Dactylis glomerata
Red clover	Trifolium pratense
White clover	Trifolium repens.

(b) Some of the above species have different strains, some more highly producing than others. Does the strain with the highest potential production still produce better than the poorer strain when the conditions are not optimum, or are the lower producers more tolerant of conditions less ideal as far as soil reaction is concerned?

(c) When any of these pasture species have different strains, do these have the same optimum pH or does each strain have a different level?

3. General Outline of Experiment.

It was planned to make a soil acid by artificial means till certain levels of Hydrogen-ion concentration were reached, then in each of these resultant soils to grow samples of all the pasture species under consideration. These plants could then be cut as required and the growth measured by weighing the herbage.

After much consideration it was decided that , although plant growth in pots may not always reproduce results "in the field", in this case soil in situ would not be satisfactory, as while the depth to which soil acidification can be controlled is limited, grass and clover roots extend to a very considerable depth under our conditions. (Jacques, 1941.)

Regarding the method of making the soil more acid. "Sulphur is sometimes used commercially for this purpose, and is changed by soil bacteria into sulphuric acid. Aluminium sulphate is sometimes applied, or fertilisers such as Ammonium sulphate which leaves an acid residue on the soil." (Work, 1945) As such methods would be slow in taking effect and final reation could not be easily controlled, it was decided to use sulphuric acid directly instead of using another substance and waiting for it to be converted into this acid by natural forces. After this treatment had been carried out, it was discovered that straight acid applications had also been used by Reid (1932) and had been found quite effective.

It was decided that initially no attempt would be made to add any nutrients to the soil but to make the growth of the plants a measure of the reaction of the plant to the Hydrogen-ion concentration and to any other conditions resulting from the soil treatment.

The plants to be used in the experiment were some of the main pasture species, and the actual plants were to be selected from lines of known history, so that they were representative of the species or strains being tested. To aid in lessening variation between plants in any species, single known plants were to be broken into clones and these used, so that in effect one had the same plants growing under the conditions resulting from each individual treatment.

4. Time and Place of Work.

This work was carried out at the Station of the Grasslands Division, Plant Research Bureau, Department of Scientific and Industrial Research, situated in Fitzherbert West, Palmerston North. The preliminary work began in October, 1945 and the last measurements of the plants were taken in June, 1947.

II. REVIEW OF LITERATURE.

Soil Acidity.

A complete review of the literature dealing with acid soils and their effects on plant growth would be a full scale work in itself. However an attempt is made here to give a good cross section of such literature as a background for the present work, and in order to help explain the results obtained in the experiments undertaken.

As stated in an earlier section, (Section 1, Par. 1.) soil acidity depends on the relative concentrations of Hydrogen-ions and Hydroxyl-ions in the soil solution. If there are equal proportions of each the soil is neutral; if Hydroxyl-ions are in excess the soil is alkaline, but if Hydrogen-ions are in excess the soil is acid. Reid (1932) states that "the term 'reaction' and 'pH value' are used to express the condition of the soil with respect to acidity, neutrality or alkalinity. A soil of pH value of 7.0 is neutral - that is, it is neither acid nor alkaline. A soil whose reaction is expressed by numbers lower than 7.0 is acid and the lower the number the greater the acidity. Likewise a soil whose reaction is expressed by a number higher than 7.0 is alkaline , and the higher the number the greater the alkalinity."

In humid regions (25 inches or more annual rainfall) soils gradually become more acid, the rate at which acidity develops depending on the amount of the rainfall, the type of the soil, and the nature of the native material from which the soil is derived (Noer, 1928.). This gradual acidification is due to the leaching of the soluble alkaline material from the soil - accentuated by the dissolving and replacing action of the carbonic acid in the percolating water which results in a predominance of acidic material and the residual soil thus gradually becomes more acid in character. (Noer, 1928,) (Hughes, Hodgson and Harris, 1939.) Noer also states that the annual loss of lime through leaching is often in the nature of 200 to 500 pounds of calcium carbonate. Lyon and Buckman (1943) express the above gradual acidification of humid soils by the following diagram:-

$$\boxed{\text{Micelle}}\ Ca^{++} + 2,H_2\ CO_3 = \boxed{\text{Micelle}}\ {}^{H+}_{H+} + Ca\,(HCO_3)_2$$

Clay high in replacable calcium.

Clay with increase in hydrogen and decrease in calcium-ions.

Soluble calcium bicarbonate readily leached.

The removal of the calcium bicarbonate by drainage causes the equation to move to the right and the continual assumption of Hydrogen-ions by the colloidal clay at the expense of the calcium, tends by equilibrium to increase the Hydrogen-ion concentration of the soil solution and the pH of the soil is gradually lowered. Lyon & Buckman (1943) stress this acidification with the following terms:- "In other words, a persistent and unremitting inclination towards acidity and its intensification exists in humid-region soils"

In agricultural practice, many common methods of preparation of ground for cropping tend towards increasing soil acidity, and the following are worthy of mention; Soil cultivation (Lyon and Buckman 1943); Ploughing under crops such as vetch for green manuring purposes (Reynolds, Cowley and Smith, 1945); Leaving ground fallow (Lyon & Buckman 1943) (Reynolds and Smith, 1946), and the use of certain fertilisers such as Sulphate of Ammonia, Ammonium phosphate, dried blood, acid phosphates (slight effect) as well as the majority of the Potash salts (Noer, 1928) (Lyon & Buckman, 1943) (Work, 1945.).

From the foregoing it is clearly seen, that in parts of the world that have a reasonable rainfall and where agriculture is carried out, there is a continual tendency towards an increase in the acidity of the soil solution.

If it considered necessary the acidity can be reduced by heavy liming or using fertilisers such as nitrate of soda, basic slag or calcium nitrate that leave a basic residue in the soil. (Noer, 1928) (Lyon & Buckman, 1943).

Apart from the above normal practices, it is sometimes desired to increase the acidity markedly in playing greens (Noer, 1928), (Madden, 1939); to get the acidity to the level where a good playing turf is readily produced (Monteith, 1932) (Metson and Gibbs, 1946), (Levy, 1939); to favour some particular plants such as Azaleas, Rhododendrons or Blueberries (Gardner, 1942); to aid in control of some plant diseases such as potato scab (Work, 1945), (Lyon & Buckman, 1943); or for purely experimental purposes. This acidification has often been carried out by addition of Sulphate of Ammonia to the soil (Doak, 1937), (Metson and Gibbs, 1946), (Noer, 1928), (Mann, 1937). In one case (Metson and Gibbs, 1946) the acidity, as represented by the pH value, changed from pH 6.0 to 4.8 with nine yearly applications at the rate of six hundredweight per acre, while in another (Mann, 1937), the pH level dropped from 6.1 to 4.4 with a lighter amount applied annually for nearly fifty years. Sulphate of iron is also used to increase acidity and is particularly useful for lawns and playing greens when combined with Sulphate of Ammonia (Metson and Gibbs, 1946), (Lyon & Buckman, 1943). Aluminium sulphate may also be used occasionally on a commercial scale (Work, 1945), but the most important chemical of all is sulphur, (Noer, 1928), (Work, 1945), (Lyon & Buckman, 1943). Most of the sulphates when added to the soil form sulphuric acid by hydrolysis (Reid, 1932), (Lyon & Buckman, 1943), and it is mainly this acid that drastically lowers the pH of the soil. When flowers of sulphur are applied "this usually undergoes vigorous microbial oxidation in the soil" finally forming sulphuric acid, "and under favourable conditions is four or five times more effective in developing acidity than ferrous sulphate" (Lyon & Buckman).

It will be observed that with nearly all the above methods of increasing soil acidity the final active reagent is sulphuric acid - so in order to speed up the acidification in the present experiment and to keep the process fairly well controlled it was decided to use sulphuric acid as a solution to be added directly to the soil. At a later date it was discovered that the same material had also been used by Reid (1932), but she had not given details to show just how this acidification was carried out. In the same paper Reid reports trying hydrochloric acid as well as sulphuric, but found that the plants in soil acidified with hydrochloric acid were never as vigorous as those in soil of the same pH that had been treated with sulphuric acid. This she explained as possibly being due to the higher toxicity of chlorides than sulphates where plants are concerned, or else, to the fact that the less soluble sulphates may not enter the plants as readily as the chlorides under similar conditions. Reid also reports that a certain clay soil produced plants that grew fairly well at a pH level between 4.0 and 4.6 when this was produced slowly using flowers of Sulphur, but did not produce actively growing plants at the same levels of acidity when this was produced by the application of sulphuric acid direct. She suggests this difference may be due to the injuring effect of the harsh acid; or the sudden change in pH resulting from this on the micro organisms in the soil, while when the pH is changed slowly the organisms may be more able to become adjusted to the changing conditions. Lundegardh (1931) also reports having added different quantities of hydrochloric acid to soil in order to change the level of acidity and to produce the range of pH levels between 4.4 and 6.8. Reid (1932) used phosphoric acid on some soils to produce acidity and found that by this method good growth was obtained at quite low pH levels. She explained the superior results by this method as being due to the extra high level of available phosphate in the soil.

When comparing soil acidity levels taken at different times of the year, it must be noted that the measured pH of a soil exposed to climatic conditions fluctuates from time to time. Minor changes of acidity occur with alteration in moisture content (Smith & Robertson, 1931), but the main fluctuation is seasonal. Lutz & Chandler (1946), state that seasonal variations in soil pH are probably related to climatic conditions and to the nature of the vegetation. Nehring (1934), recorded that highest pH values were found during the winter, and the lowest in summer and that variations between these two extremes might be as great as 0.8 pH. Lyon & Buckman (1943), report that soil pH decreases as summer advances, especially if land is under cultivation and they attribute this to the activities of soil micro-organisms. When land is under vegetation, the acidity may be least in the autumn, and Joffe (1935) states that in forest lands this is due to the release of bases from freshly fallen leaves. Smith & Robertson (1931), found that the soil acidity moved in the same direction whether the soil was fallowed or planted and the following are their conclusions:- "In the early part of the season when accumulation of salts takes place on account of the rise in temperature, the acidity of soil increases, irrespective of climatic factors. Where plants are growing that accumulation is not so great and the increase in acidity is not so marked. Towards the end of the growing season, climatic factors, and particularly rainfall, appear to be responsible for irregular fluctuations, but there is a general tendency for the acidity to decrease. Finally the pH value, like the concentration of salts becomes approximately the same for both planted and fallow soils, and not far removed from that at the beginning of the season. It seems therefore, that variations in soil acidity are definitely connected with changes in the quantities of electrolytes present, and that the effect of the plant is due, at least in part, to absorption of salts.

It is possible , however, that bicarbonates formed as a result of plant growth also exert some influence."

There appears to be little record of any direct ability of plants to cause changes of the pH of their growing medium, apart from observations using water cultures. When water cultures are used, buffering is often slight and the uptake of nutrients may cause minor acidity alterations. Lundegardh (1931), in reporting work by Weiss, states however that a well buffered alkaline solution would not support the growth of maize and oats since the plants were unable to change the pH, while in a weakly buffered solution the pH was shifted by the plants themselves into the region of optimum growth.

2. Hydrogen-ion Concentration and Plant Growth.

Let us now consider the effect of the soil on plants growing in the soil, that is, the real importance of soil acidity in agriculture. In practice it is very difficult when dealing with the soil to determine just how much of the effect observed on the plant is due directly to the Hydrogen-ion concentration, because so many factors are interrelated. The acidity of the soil solution may directly affect the plant growth; it may result in secondary nutritional effects or it may influence the health activities of the micro- and macro-organisms of the soil. Therefore any resultant plant growth observed may be due to any one of these or any combination of them. In an attempt to distinguish between causes of observed effects of acidity on plants, much work has been carried out using nutrient solutions where micro-organisms play no part in plant nutrition, and where it is possible to alter either the nutrient supply or the hydrogen-ion concentration independently. Using this method, Arnon and Johnson (1942) in a comprehensive experiment found complete failure of plant growth at both extremes of acidity and alkalinity - pH 3 and 9, while between pH 4 and 8 fluctuations in hydrogen-ion concentrations were well tolerated by the plants, provided an adequate supply of nutrients was maintained.

They found that there appeared to be optimum growth of tomato, lettuce and Bermuda grass at a pH of about 6, though Bermuda grass was still very good at pH 4. Guest and Chapman (1945), report that Hydrogen- and Hydroxyl-ion concentrations corresponding to pH levels from 4 to 9 exerted no appreciable direct ill effects on the growth of sweet oranges. Duggar (1920), found also with wheat, corn and Canadian field peas, that under favourable conditions they gave excellent growth even when the pH of solutions varied from 4.5 to 7.1. Working with different vegetables, Hewitt (1945) reports that in solutions with complete nutrients, growth was vigorous and normal despite a pH of 3.6. Tarr and Noble (1922) also reported that pH 3 was prohibitive to the growth of seedlings of wheat, corn and soya beans pH 5, but at a pH of 6 chlorosis began to appear in all these plants. Powers (1927), found that the maximum development of Hungarian vetch was at pH 5.3, spearmint at pH 6.0 and lucerne and alsike between pH 5.5 - 6.0. Pizer (1945), dealing with natural soils reported that ryegrass, tomatoes and potatoes were all able to grow in strongly acid conditions (pH 4.5 - 5.2) but preferred a moderately to slightly acid medium (pH 5.3 - 5.7 - 6.4). He also stated that at pH 4.2 gorse, bracken, bramble and sedges thrived while at pH 3.9 heather, gorse and silver birch were often found. Noer (1928), also working with soil, found that clovers grew best at pH range from 6 to 8 while at about pH 5 they were usually unable to exist and he doubted whether they could thrive even at a pH of 5.5 to 6.0. Hoagland (1923), reported that barley, cucumber and peas all grew best when the nutrient solutions were slightly acid. Lundegardh (1945), in measurements of growth of wheat roots found that the pH series gave one peaked curves with optimum levels at pH 6 in a solution with metalic ions (Na or K.), and pH 5 in solutions without such metalic ions.

On the other hand, Salter & McIlvane (1917), record that with the growth of wheat seedlings in nutrient solutions at varying acidities there was observed a double maximum curve of growth, with a minimum between the two peaks at pH 6.

Arrhenius (1922), found similarily that as well as poor growth at high degrees of acidity and alkalinity there was often noticed a toxic region between these two extremes. Robbins (1923) came to a similar conclusion but stated that this double curve of growth might not always be observed, even if present, as so many conditions may conceal the minimum between the two maxima. He recorded that temperature, water supply and salt content might limit growth, and the maximum and minimum points might not be distinguished. He also stated that this point of minimum growth might correspond to the isoelectric point for the plant tissue concerned.

Certain workers, McCall and Haag (1920), and Meier and Hadstead (1921), obtained no correlation between yield of wheat and the pH, or change of pH. Mann (1937), working with barley in soil made acid with Sulphate of Ammonia to pH 4.4, stated that the "most striking result of an injurious degree of acidity in the soil lies in the effect on formation of the ears and on the grain contained in them. At a pH of 4.4 grains were rarely more than two per head, but the number of shoots per plant and even the number of heads were not so directly influenced by the acidity".

Lundegardh and Burstrom (1945), found that glucose consumption by wheat roots decreased rapidly as the pH was lowered, and stated that this rapid decrease was believed due to the fact that growth intensity was regulated by the pH value of the surface layer of the root which in turn was directly influenced by the pH of the medium. Work by Chodat (1915), Mervius (1924, 1927), and Olsen (1923), also points towards the fact that the immediate concentration of Hydrogen-ions in the soil, apart from secondary factors, has a decisive influence upon the floristic composition of the vegetation of given areas (Koslowska, 1934).

Olsen (1921), using culture solutions, found that Dechampsia flexuosa had maximum growth at pH 4, while growth at pH 3 was nearly the same as that at pH 5 and at pH 2.5 it was better than at pH 7. In the field he found this species only in soils with pH level below 4.9, while a different species, Deschampsia caespitosa, was found at pH levels only above 5. Olsen also found that with Hordeum distichum in culture solutions the optimum pH was between 5.5 and 6.5 but growth decreased rapidly on both acid and alkaline sides of this optimum. Thus it appears true, as Lundegardh (1931) states in reveiwing the work of Arrhenius (1925) and Stark (1928), that the optimum pH is specific for different species of plants, and he goes further and says it is also specific for different strains of the same species.

It is difficult however to understand completely the effect of local conditions on the apparent optimum range of pH for certain plants. Thus Britton (1942), reporting work by Kreyberg, shows how red clover growing in a "humid" climate has an optimum pH of 8.3 to 8.7 while the same species growing in a "moist" climate and light sandy soil has an optimum range of pH 6.0 to 6.8. Reid (1932), reports a similar case in which Metropolitan bent was grown on two different soils and the growth on the clay soil was most rapid at pH 8.3 while on a compost mixture, growth was most rapid at pH 4.5 and dropped sharply away on both sides of this level.

3. Hydrogen-ion Concentration and Nutrient Availability.

Many workers attribute the effect of acid soils on plants to nutrient deficiencies or chemical toxicities, and Hewitt (1945) says the following require consideration, apart from direct acidity effects and biotic factors:-

(a) Greatly increased availability of such elements as manganese, iron, zinc, copper and aluminium to point of toxicity.

(b) Fixation of phosphate which may become deficient.

(c) Molybdenum deficiency. This element appears less available under acid conditions and lime seems important in its uptake.

(d) Low calcium status resulting in calcium deficiency.

(e) Low base status resulting in complex calcium, magnesium, potassium and sodium deficiencies.

Hewitt (1945), grew cauliflowers and runner beans in different nutrient solutions, and found that the typical symptoms produced by these crops in acid soils were reproduced in sand cultures by supplying manganese in 12 to 25 parts per million with a low calcium level. He found too that increased calcium supply reduced the severity of the manganese toxicity. In connection with manganese, it is of interest that Marshall (1944) decided that the uptake of this element depended largely on the pH of the soil and on the exchangeable manganese present. He did find however that in each of the two soils studied, the manganese was in a different form, for in one it was liberated by acid conditions but in the other it was not. It is worthy of note too that Walsh (1945) found that at higher pH levels, grasses often showed chlorotic symtoms that were corrected by spraying with manganese sulphate, and he also recorded that certain strains of some grasses reacted differently from other strains.

With regard to aluminium, it is a recognised fact that this element may become so active when the pH of a mineral soil is low, that it is extremely toxic to certain plants, (Lyon & Buckman, 1943). Hartwell and Pember (1918), report that the effects of acid soil on both barley and rye appear to be due to aluminium toxicity, while McLean and Gilbert (1928), working with nutrient solutions, found that aluminium was stimulating to plants at low concentration but toxic at high ones. The aluminium still remained toxic even though the acidity was less than that represented by pH 6.

It is a well known fact that phosphates are readily fixed by aluminium in an acid soil, but the reverse situation is not usually realised. However, McLean and Gilbert (1928), reported that souble phosphates in concentrations equivalent to that of the aluminium, completely counteracted the aluminium toxicity and that plants then grew normally. Lundegardh (1931), though not mentioning aluminium specifically, agrees that acid phosphates help to neutralize the harmful effects of an excess of Hydrogen-ions in the soil.

With regard to the availability of phosphates in acid soils, Pizer (1945), states that at low pH, both potash and phosphate are usually low or very low, and even under good heath where the organic matter is high a soil at pH 4.2 had medium to high potash content but very low phosphate. Lyon & Buckman (1943), state that at pH levels above 7.0 phosphate may be fixed in complex calcium phosphates unavailable to most plants, while if the level is much below pH 5.0, the unavailable iron and aluminium phosphates may be formed. They suggest further that for regulation of the phosphorous nutrition of plants on average soils the pH of the soil should be kept between 5.6 and 6.5. Reid (1932), working with bent grasses, found that on the clay soil used, the supply of available phosphorus was the chief factor causing variation in growth at different reactions and a graph showing the available phosphate at varying acidities was similar to that showing the growth at these pH levels. As mentioned previously, Reid reported that she used phosphoric acid to bring soil pH down to 4.2 and the resultant growth was very good compared with that on the soil acidified to the same level with sulphuric or hydrochloric acids.

The following chart, reproduced from Work (1945) was first published by Pettinger (1935) and gives a good visual representation of the effect of acidity on the availability of some major nutrients.

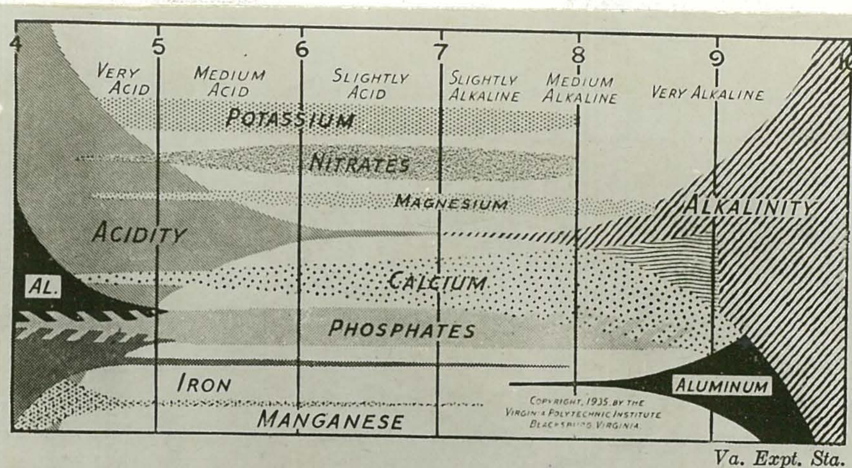


FIG. 4. Soil reaction chart. Figures at top are *p*H values. Areas at ends, narrowing to center, represent corresponding acidity and alkalinity values. Other shaded areas roughly represent availability of elements corresponding to soil reaction. This chart represents general relations only. Factors such as moisture, minerals, organic matter, or other soil characters may change the picture materially.

Apart from these main nutrients whose availability is affected by change in Hydrogen-ion concentration, certain of the "minor" elements are also important. Thus Davies (1945), has reported that in very acid soils in New Zealand a molybdenum deficiency has been observed in cauliflowers. Boron too has its availability influenced by pH and many workers have recorded observations on lime induced boron deficiency. (Scharrer and Schrapp, 1934), (Pervis, 1939), (Midgley and Dunklee, 1939), (Bobko, 135, 1936), Abatorova, 1936). Some of these people go so far as to suggest that all bad effects on plants due to overliming are really results of an induced boron deficiency. In New Zealand there is one good example that appears to illustrate the fact that the amount of boron present for effective plant growth requires to be higher as the pH of the soil increases. Thus in Central Otago where the pH of the soil was 7.2 unhealthy fruit resulted when the boron content was 1.4 p.p.m., while nearby an area of pH 6.3 gave perfectly healthy fruit despite a boron content of 1.2 p.p.m. (Askew, Thomson and Kidson, 1936). It appears also that copper, zinc and manganese react in a somewhat similar way and become unavailable to plants if the soil reaction rises above neutrality.

In addition to the altered availability of certain nutrients with different levels of acidity, it appears that the ability of plants to absorb nutrients, even if available, depends to a certain extent on the Hydrogen-ion concentration of the medium. Working on this effect, Arnon, Fratyke and Johnson (1942) decided that in culture solutions, pH 3 caused direct injury to plant roots while a pH of from 4 to 9 had no profound effects on the absorption of magnesium, potassium or nitrate. Where calcium was concerned however they found that using both tomato and lettuce plants, there was much lower absorption from strongly acid solutions (pH 4 and 5) than at higher pH values. It appears, on the other hand, as if acid conditions may facilitate phosphate absorption by plants as recorded by Sekera (1928). Tidmore (1930) working with maize and wheat in culture solutions, also observed that greater absorption of phosphate took place from acid solutions than from alkaline ones, but stated that variation in the pH from 4 to 6 had little effect on the rate of the absorption. Britton (1942), also records that the phosphorus intake of plants is fairly sensitive to changes in pH of the nutrient medium, and that the rate of absorption of certain sections by the root hairs increases with decreasing pH values of the nutrient.

In some way that is unexplained at present, calcium often appears to remove the ill effects of Hydrogen-ions in plants and fungi, and Lundegardh (1931) states that the addition of calcium usually moves the optimum pH towards the acid side. He illustrates this with an example in which the optimum pH for wheat in a certain soil was 6.8 but after the application of 0.5 grams of calium chloride solution to 50 grams of soil, the optimum pH was reduced to 6.1. Arnon and Johnson (1942) working with nutrient solutions obtained similar results, and recorded that with tomato, lettuce and Bermuda grass the best growth at pH 4 was with a high level of calcium, and this was as good as the growth at pH 5 with a low calcium supply.

No such response was observed at pH 6. Albrecht (1937, 1939), working with legumes in acid soils, concluded that the lack of nodulation and nitrogen fixation by legumes on acid soils was due both to the high concentration of Hydrogen-ions and to the low level of calcium, and that the addition of calcium as a neutral salt was two and a half times as efficient in promoting the growth of plants as a decrease in the Hydrogen-ion concentration. As far as the nodules themselves were concerned, Albrecht reported that at no level of calcium could nodules be obtained below pH 5.5, but at higher values calcium was more effective than a decrease in acidity in stimulating their formation. Albrecht (1941), records that forms of calcium compounds other than the carbonate, that did not neutralize soil acidity, would produce normal plant growth in acid soils, and in another paper (1943) concludes that "the so called plant injury by soil acidity is largely a matter of deficiency of the plant nutrient calcium." This is however at variance with results of Gedroiz (1931) and Muyake (1924) who found that gypsum did not improve plant growth on acid soils though lime did. However Fried and Peech (1946), after getting similar results even though the gypsum increased the available calcium in the soil solution to a greater extent than the lime did, decided that the poor growth in acid soils might be due to calcium deficiency within the plant, even though there was adequate calcium in the soil. They recorded that the plants used were unable to absorb the calcium from acid soil even though it was present in adequate amounts as a soluble salt. They decided further that manganese appeared to prevent the uptake of available calcium by the plant under acid conditions.

4. <u>Soil Reaction and Biological Effects.</u>

Certain workers have found that detrimental effects of acid soils on plant growth may be due indirectly to effects on micro-organisms or soil fungi.

Thus Rayner and Neilson Jones (1944) found that the growth of conifers on certain acid soils was stopped owing to inhibition of mycorrhizal fungi associations. Lindquist (1931) working with "calcifuge" plants, decided that the occurrence of these so called "acid plants" depended on the possibility of the possession by their roots of a mycorrhiza exclusively connected with acid humus. This mycorrhizal nutrition may play a considerable part in the ability of certain grasses to survive and even thrive under very acid conditions, but little work appears to have been done on the subject, and it may be quite a fertile field for research.

As far as the symbiotic Rhizobia of legumes are concerned, it is the general opinion as stated earlier (Albrecht 1937, 1939), that despite ample available nutrients, the minimum pH for nodule formation is 5.5, but Bryan (1922) found that although nodule formation on soya bean was best at pH 6.5 the limits to their formation were pH 3.6 and pH 8.

Certain other micro-organisms in the soil are very sensitive to changes in soil acidity, and the example of the Azotobacter which fix certain free nitrogen from the soil atmosphere can be quoted. Gainey and Fowler (1945), stated that the Hydrogen-ion concentration of the medium exercised a profound influence of the growth of this organism. They found the maximum acidity compatible with growth varied somewhat with different strains, but in general fell within the range pH 5.5 to 6.0, and the growth was markedly retarded within a few tenths pH unit of the critical Hydrogen-ion concentration. Christensen (1914), similarly found that Azotobacter disappeared altogether below pH 5.8, while their development decreased rapidly below 6.5.

Of importance in turf work is the fact that the organisms bringing about the decomposition of cellulose become almost inactive at pH 6.0, and the result of this inactivity at pH levels below this is the formation of the "mat" of grass residues that seems so desirable in the formation of a hard wearing turf for playing greens. Nitrifying bacteria however, seem able to flourish in acid soils (Blair and Prince 1922), but Britton (1942) states that at pH 4.5 nitrification has practically ceased, although ammonifying organisms are still fairly active even at pH as low as 3.5. Parbery (1946) found that at pH 4.85 nitrification was still effective, and the addition of nitrogenous fertilisers to his pots of plants eventually proved to have a recessive influence on plant growth. De Silva (1934) in a comprehensive work on the distribution of certain plant species as correlated with chemical properties in the soil, observed that while nitrifying bacteria normally seemed to flourish in soils with calcium carbonate and appreciable exchangeable calcium combined with low soil acidity, they were sometimes found to function, though with reduced vigour, in soils which were quite acid (pH 4.4), and which contained no calcium carbonate and little exchangeable calcium. Bear (1917) decided that "the division of plants into acid and alkaline species depended on the ability of some plants to absorb from the soil ammonical salts derived from humus which will not yield to the process of nitrification while other species need the nitrates in which alkaline soils abound". It is usually considered that legumes require a soil near neutrality for their growth (Britton, 1942), but Ellet and Carrier (1915) recorded that Trifolium repens tolerated a high degree of soil acidity. Working with the same plant, Bates (1934) grew plants successfully from seed in soil at pH 3.0 although development was fairly poor. He also produced some interesting effects with the roots of white clover by placing a layer of soil at pH 3 between layers at pH 6.0 or 7.0 in which case there was no development of secondary roots in the acid soil at whatever depth the acid layer was put.

From all this literature, it would appear as if most plants can stand a fairly wide range of actual Hydrogen-ion concentration in their growing medium as long as nutrient and other conditions are kept favourable , and that any detrimental effects noticed on plant growth at any particular level of acidity may be due to any one of a large number of factors or to a complex combination of two or more, depending on the particular crop, soil and climate. The most important factors causing bad effects on plant growth in acid soils appear however, to be direct factors such as toxicity of materials such as iron, aluminium or manganese or nutrient deficiencies due either to the unavailability of certain elements at particular levels of acidity or to the inability of the plant to absorb and use the available food supplies.

5. Hydrogen-ion Concentration and Seed Germination.

Apart from the wide interest in plant growth in acid soils, some workers have experimented with germination ability at different pH levels. In this connection Arrhenius (1922), working with wheat, found that the best percentage germination was obtained at pH 5.0, then above and below this level germination fell off, but rose again on the alkaline side and was fairly good at pH 7. However the fastest germination obtained was at pH 7. He weighed the growth of roots and tops of plants after growth was well established and obtained greatest growth of both at pH 5. The same worker in a similar experiment with radish seed, found the germination at pH 10.0 was superior to any other, though the rate of germination was best at pH 8.0. However both the final germination and rate of germination was good between pH 7 and 10. The greatest weight of roots recorded was from pH 7.0 and the heaviest tops grew at pH 9.0. Lundegardh (1931) in a similar experiment with wheat, represents his results with a graph showing germination levels between pH 3.5 and 6.9. The curve rises from 3.5 to 4.9 where the germination was 60 per cent, falls at pH 5.6 then begins to rise again and reaches a maximum of 75 per cent at his final level tested, pH 6.9.

Bates (1930), in a general statement gives the only reference found to germination of pasture species in acid soils, by stating that it was a "generally accepted fact, that in the case of several grasses, a thin layer of neutral or alkaline soil was sufficient to stimulate germination and establishment on an acid soil."

MATERIALS USED.

1. The Soil.

The soil for this study was a friable silt loam containing a good proportion of organic matter. It was a virgin soil from near the bank of the Tiritea stream where the latter flows through the Grasslands Station area. This part of the Station when acquired by the Grasslands Division at the end of 1940, was a virtual wilderness of scrub, blackberry and native trees. This was gradually cleared and the area periodically grazed by stock as pasture plants became established. To obtain the soil for use in the present experiment the turf was skimmed off part of the area and the earth down to spade depth dug out, put through a screen to remove large stones, roots etc., then loaded on a truck and taken into a shed.

2. Flower Pots.

The flower pots used in this experiment were eight inch ones, because it was considered no smaller size would be large enough to provide nutrients for the plants over a period of twelve months without the plants becoming pot bound. There was no choice possible when selecting the type to be used because only one kind was available, unglazed porous clay pots, and these were obtained from F. Coopers, Dixon Street, Wellington. These were of course well washed before using.

3. Chemicals.

The main chemical used was the acid required to alter the Hydrogen-ion concentration of the soil. This was "Analar" Sulphuric acid with the following maximum limits of impurities:-

Non volatile matter	0.0025 per cent.
Chloride	0.003 " "
Nitrate	0.00001 "

Selenium	0.001	per cent
Heavy metals	0.0002	" "
Iron	0.0001	" "
Ammonia	0.0005	" "
Oxygen absorbed	0.0001	" "
Arsenic	0.00001	" "

4. Plants.

Plants used in this experiment were of known origin, and nearly all had been growing on the Grasslands Division Station for a considerable time, so that the type and character of each was accurately known. The only exception to this was in the case of Broad red clover where the original plants died out, and were then replaced by seedlings from a uniform line developed by the Plant Breeder of the Grasslands Division.

5. Water Supply.

The water supply at the Grasslands Division comes from the Tiritea stream after reticulation through the "Town supply" system and as this was found by simple chemical tests to contain a certain proportion of carbonates and bases, it was though inadvisable to use this on the plants. Finally a galvanised tank was installed under a down pipe from a painted iron roof and rain water was collected for use in watering the plants. However, during a number of prolonged dry spells there was insufficient rain water to meet requirements and it was then necessary to use the Town supply. In all watering, in order to try and avoid undue leaching in the pots, these later were stood in trays, the water was put into these trays and drawn up to the soil and plants as required.

6. Other Equipment. (a) Trays:

The trays used in watering the pots had another and an important use. They were made of 24 gauge galvanised iron and were 18 inches by 30 inches, with walls 4 inches high.

When the pots were stood in these, the plant roots were unable to reach the soil, so that all the nutrients required by the plants, had to come from the treated soil in the pots. If the pots had been stood directly on the ground, the roots of the more strongly growing plants would very soon have grown through the drainage hole in the base of the pots and penetrated the soil below. If this had occurred, the growth of the plants would not have been a true indication of the reaction of the plants to the treated soils.

(b) Cutting Equipment.)
(c) Weighing Equipment.) See later under Section VI.
(d) Drying Ovens.)

IV. PLAN OF EXPERIMENT.

1. Plant Species and Strains Used.

As mentioned earlier, the pasture species used are some of the most important ones in New Zealand agriculture and all are in wide-spread use right through this country. Most of the strains of these species used were "Nucleus" in origin - that is, they would be the foundation of lines of seed to be produced for ultimately coming on to the market at the head of the certification system. Where possible a contrasting strain that in practice is normally inferior in type and low in production, has been used also, and this has been done in the case of Perennial ryegrass and White clover. In the Red clover species, two varieties have been used - "Broad red clover" or "Cowgrass" and "Montgomery Late Flowering" - but the plants of both these used were of Nucleus strain. In the case of the Cocksfoot species, two contrasting strains have been used. The Danish strain, while being inferior in type as far as New Zealand agricultural practice is concerned, is so mainly because of its coarse open growth and its liability to "winter-burn" in cold weather, and is not necessarily a much lower producer at other times of the year.

The following table gives details of the species and strains used in this experiment, and the identification numbers and letters of the individual plants chosen:-

Species.	Strain.	Experimental Designation.	Station Number.
Perennial ryegrass (Lolium perenne).	Nucleus	"A"	A94/57
Perennial ryegrass)Lolium perenne)	Type III	"B"	Ba 6621
Italian ryegrass (Lolium multiflorum)	Nucleus	"C"	B1782/4
Short Rotation ryegrass (Lolium perenne. L. multiflorum)	Nucleus	"D"	E366/4
Cocksfoot (Dactylis glomerata)	Nucleus	"E"	K24/161
Cocksfoot (Dactylis glomerata)	Danish	"F"	Bc 466

Species.	Strain.	Experimental Designation.	Station Number.
Red Clover (Trifolium pratense)	Nucleus Broad	"G"	F270/4
	Later replaced by seedlings of line		Aa 596
Red Clover (Trifolium pratense)	Nucleus Montgomery	"H"	Aa 581
White Clover (Trifolium repens)	Nucleus Type I	"I"	C472g3/186
White Clover (Trifolium repens)	Nucleus Type II	"K"	C474/41

For the sake of convenience in recording weights and for comparisons etc., the letter given as the "Experimental Designation" has been used to identify each plant species or strain throughout this experiment.

2. Treatments.

The soil treatment were designed to produce five levels of soil acidity, ranging from approximately neutral down to about the maximum acidity found in mineral soil in New Zealand. The following were the five treatments and the letters used in this experiment to represent each.

Treatment.	Experimental Designation.
Neutral	"N"
Sligttly Acid	"S"
Moderately Acid	"M"
Very Acid	"V"
Extremely Acid	"X"

The appropriate identifying letter was printed on each pot of soil so that there could be no mixing of the treatments.

3. Replications.

In this experiment the same number of replications was used as there are treatments, i.e. five. Thus as there were ten plant species or strains and five treatments, five replications of each gave a total of two hundred and fifty pots.

In the case of nucleus Perennial ryegrass, Series "A" one extra replication was arranged for each treatment, so that if any soil was required for later tests or further experiments it would be possible to obtain this without upsetting the standard arrangement of five replications.

V. PREPARATION.

When the soil for the experiment was taken from the field into the shed (see section III Par. 1.), it was shovelled on to a concrete floor where one part of clean river sand was mixed with four parts of the soil, in order that the resultant mixture might be suitable for handling during later treatments. After thorough mixing the soil was placed in a sterilizing bin and sterilized with steam. The routine method of sterilizing at this Station consists of covering the soil in the bin with sacks, then with a wooden lid. The steam is then turned on slowly, and after this begins to come through the soil, treatment is continued for twenty minutes. In a check of the temperature reached by the soil, the soil rose to 209 - 210° F in 20 minutes. It was kept at this temperature for a further twenty minutes before removing from the bin. Such a treatment ensures the killing of all weed seeds in the soil. When sterilization was completed, the soil was placed in boxes 2 ft. by 1 ft. by 3 ins., and these were stacked for six weeks before further treatment.

Many preliminary tests were required to evolve a method of changing the Hydrogen-ion concentration of the soil so that the required range of acidities could be obtained. One 8 ins. pot holds over eight pounds of soil, and as at least 50 pots of each treatment were required, this involved altering the level of acidity of 400 lbs of soil in such a manner as to have every part of it at the same pH. As Sulphuric acid was to be used for the soil treatment, it was wondered whether the required change could be effected by mixing a heap of soil with acid, but this way might have had detrimental effects on the soil structure despite the addition of the sand to the soil. Then there was no convenient vessel available that could hold the required amount of soil while it was saturated with acid. Even if there had been, the centre of the soil mass might not have been reacted on as much as the outside portions.

Finally the method was evolved of placing a rubber cork in the drainage hole in the base of a single flower pot of soil and adding the required amount of acid. After a considerable number of trials involving the use of small pots, gradually increasing the size until 8 ins. ones were used, it was found that, by stopping the drainage hole and adding more acid than was required to fully saturate the soil and leaving the stopper in position a considerable length of time, equilibrium was obtained. Some of the liquid gradually seeped through the sides and base of the pots, but this method was found to give a satisfactory change in pH and all the soil in the pot was evenly changed. Seeing enough acid had to be added to each pot to more than saturate the soil, (1500 C.C.s. of acid were used to an eight inch pot of soil), it was necessary to use an altered strength of acid instead of a varied amount of acid of one strength in order to obtain different soil acidities. After considerable trials, it was decided to use acid of the following strengths :- $\frac{N}{2.5}$, $\frac{N}{5}$, $\frac{N}{10}$, $\frac{N}{20}$ and to leave one lot untreated. Concentrated "Analar" Sulphuric acid was diluted in a stainless steel vessel until [illegible] litres of "Normal" acid was obtained. Some of this was then measured into a measuring cylinder and further diluted until 1500 C.C.s. of acid of the required strength was obtained. Thus to obtain 1500 C.C.s of $\frac{N}{10}$ acid, 150 C.C.s of normal acid were put in the cylinder and this filled up to the 1500 C.C. mark with water, and well stirred. This diluted acid was then carefully poured on to a pot of soil that had the hole stopped, and after the whole was saturated about half an inch of liquid covered the surface. After twenty four hours the stopper was removed, any surplus acid drained off and the soil left for a week to allow any further chemical change to take place. Sixty pots of soil were treated at each level of acidity, the pots being filled to about 1[illegible] inches from the top in order to allow for treading.

The pots of soil that were to remain neutral were treated with water in the same manner as the others with acid, so that any changes that might have taken place through the soil being saturated for 24 hours might be common to all.

About a week after treatments were carried out, the soils, still in the pots, were thoroughly leached with water. All the pots were filled with water and allowed to drain for a day, then refilled - and this leaching was repeatedly carried out till it was considered any chemicals released by the acid would be removed from the soil. At this stage the pots were left standing for over a month to ensure stabilization within the soil, and then it was considered equilibrium would have been reached and the soil was ready for use. On June 19th, 1946, the next stage of the work was carried out. All the soil from any one treatment was poured out onto a concrete floor, and the whole mass turned three times to ensure even mixing, just in case any odd pot of soil had been affected differently in treatment. At this time one pot was filled with soil taken from all parts of the heap, and was kept for testing and any future trials that might be carried out. When the pots were emptied, they were thoroughly washed to be ready for refilling and planting.

2. Plant Preparation.

As mentioned earlier, (Section I, Par. 3), single plants of known history were to be used as far as possible and these broken up to provide even clones, so that the genetical make-up of any plant in one series, would be the same. To obtain even clones for planting into the pots, the main plants were taken out of the ground on the 7th March, 1946 and each divided up to give 56 well rooted tillers. The leaves and roots of these were trimmed, then they were planted into boxes 2' x 1' x 3", each box having 28 clones.

The boxes were well watered to settle the soil around the roots, and were kept in suitable condition for plant development until the clones were well established and ready for planting into the treated soil, about the middle of June.

Out of the 56 tillers planted, at the most only 30 were required, so that it was possible to discard any that were poorly developed and so obtain a set for final use that was as even in size as possible. In the case of the Broad red clover, virus disease destroyed all the plants in one box and as a result very little choice for even clones could be made. Although the ones actually planted in the pots appeared healthy, they too died within a few months and were replaced in September by seedling plants from a uniform line, developed by the Plant Breeder at the Grasslands Station. These plants were four months old and it was possible to chose plants all of similar type and size. Thus the plants finally measured in each treatment of any one pasture species were actually clones of a single plant of known origin, with the exception of those of Broad red clover, which were seedlings from a uniform line of seed selected for their similarity of growth.

3. Final Planting.

By the middle of June, 1946, all the soil treatments had been completed and the plants were ready for replanting, and on the 19th June the final planting was carried out.

The soil for each treatment was mixed as previously described (Section V, Par. 1.), and after the pots were washed and drained, the actual planting was begun. Pieces of broken pots or crocks were carefully placed in the bottom of each pot to cover the drainage hole and allow efficient drainage. The pot was then nearly half filled with the prepared soil and packed as evenly as possible. The two boxes containing the clones of any species to be planted were placed nearby, and the most even plants selected. These were placed carefully in the centre of the pot with the roots spread, then soil was packed around the plant till the pot was filled to within about an inch of the top. The filled pots were gently tapped on the potting bench to try and ensure even settling of the soil. The pot was then labelled with the appropriate letter to indicate the soil treatment and the prepared peg inserted to show the individual number of that plant.

After the filled pots were placed in their trays in the set arrangement they were carefully watered from above with a watering can to try and encourage intimate contact of soil and roots, and to give the plants ready water to help them overcome the transplanting. No plants showed signs of any retarding effect owing to the transplanting, but as mentioned before, (Section V, Par. 2.), the plants of Broad red clover died of virus and were replaced by seedlings on 26th September, 1946. All the plants were watered whenever the lack of sufficient rainfall made this necessary, but if the weather was continually wet and cold, plugs were removed from holes in the trays and the water removed. In this way an attempt was made to keep the water content of the soil suitable for maximum plant growth.

For ease in recording and identifying individual plants, in each treatment all the replications with any one plant strain or species were given numbers, and a peg was inserted in each pot with the identifying letter and number printed thereon. Thus the five individual replications of Short Rotation ryegrass in any treatment were labelled D.1, D.2, D.3, D.4, and D.5, These pegs used in conjuction with the treatment letter on the actual pots, enable one to pick out any plant in the series and identify it, say as C.4,V. that is, plant number four of the Italian ryegrass series in the "Very acid" treatment.

4. Arrangement.

As mentioned earlier, all pots were to be stood in metal trays and the supply of these limited the arrangement of pots that was possible. As soil variation did not require to be overcome by plot arrange ment as in a field experiment, it seemed to be more convenient to have a regular arrangement than a random one.

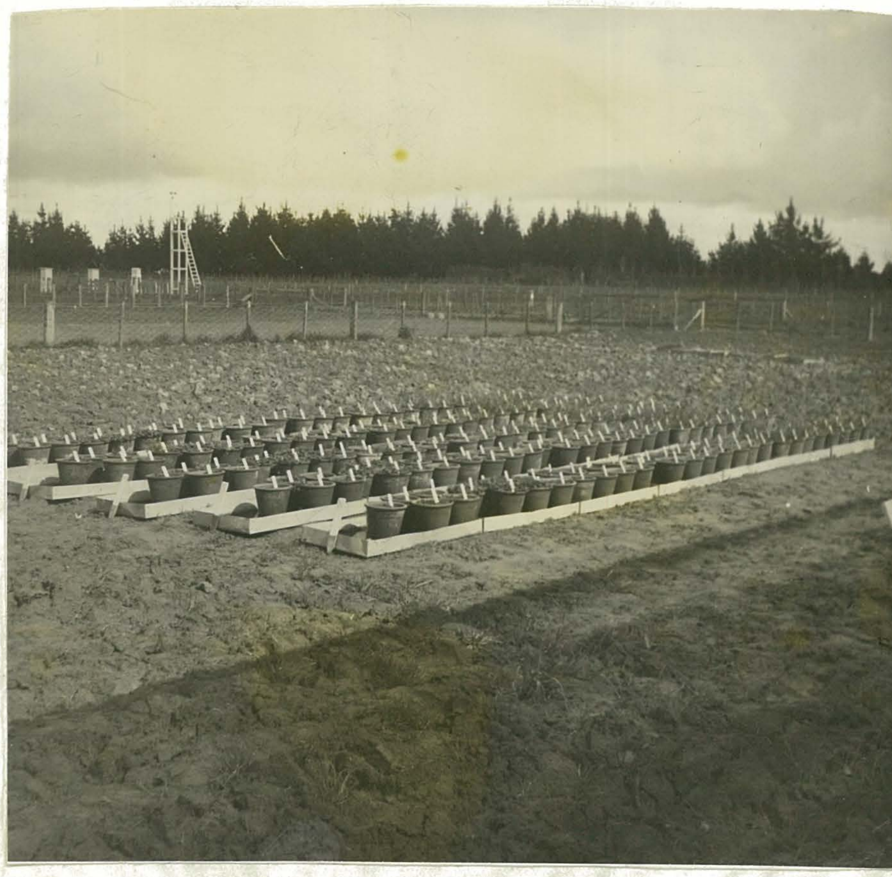
It was considered most important to keep different treatments in separate trays in case there was any difference in the water in the trays as a result of the treatments. This was because it was possible, for example, that the water round the pots of "Extremely acid" soil might become a bit acid and cause a plant in a tray containing "Neutral soil" to grow better than a similar plant in a tray containing "Medium acid" soil. It was considered wise, too, to keep grass plants in trays separate from those containing clovers in case extra nitrogen that might be excreted from the legumes should alter the grass growth. Owing to the limited number of trays available it was not possible to keep each plant species in a single tray for each treatment, but treatments were kept separate and legumes were kept divided from grasses.

Mr. I.D.Dick, Officer in Charge, Biometric Section, Department S. & I.R., agreed that although complete randomization of the pots would have been more ideal from the statisticians point of view yet the arrangement used was the best possible under the circumstances.

The arrangement of the flower pots in the metal trays was as shown on the following page:-

X		V	M		B	N
Pots arranged as in N series.		Pots arranged as in N Series.			Pots arranged as in N series.	A.1 A.2 A.3 A.4 A.5 A.6 B.1 B.2
						B.3 B.4 B.5 C.1 C.2 C.3 C.4 C.5
	......PATHWAY......			......PATHWAY......		D.1 D.2 D.3 D.4 D.5 E.1 E.2 E.3
						E.4 E.5 F.1 F.2 F.3 F.4 F.5
						G.1 G.2 G.3 G.4 G.5 H.1 H.2 H.3
						H.4 H.5 I.1 I.2 I.3 I.4 I.5
						K.1 K.2 K.3 K.4 [illegible]

The following photographs show the flower pots in position in the trays and the situation in which the trays were placed:-



Photos. 20th September, 1946.

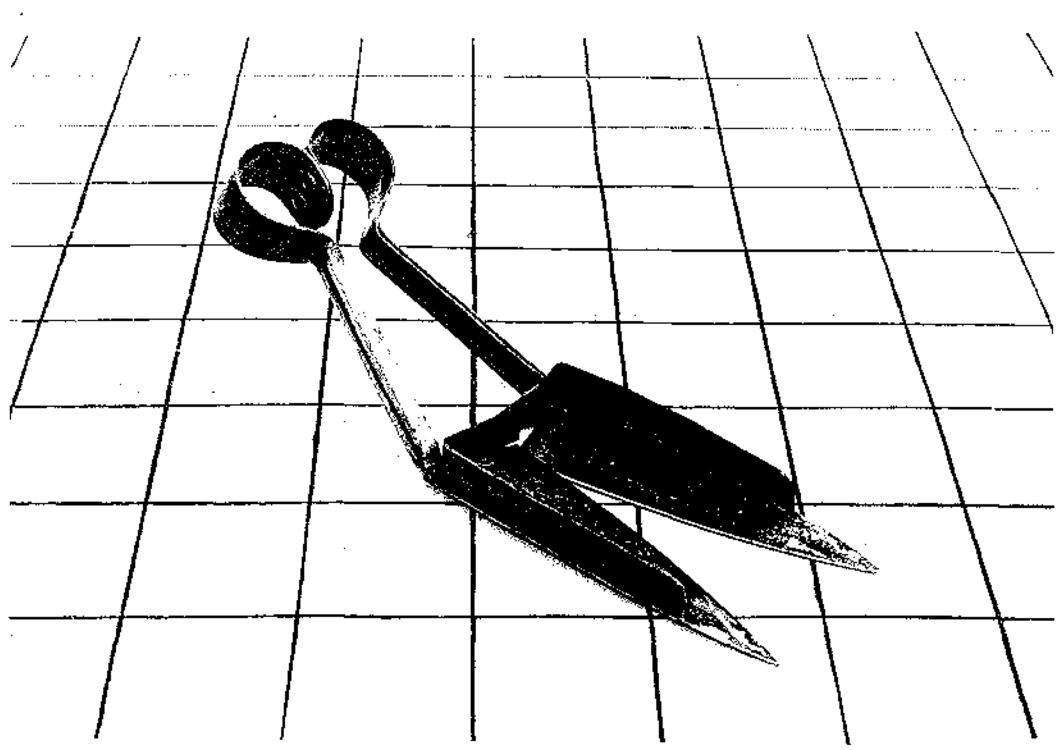
VI. CUTTING AND WEIGHING THE HERBAGE.

1. Times of Cutting.

Because of the difference in growth of the different species and strains of plants used, no set time was laid down for cutting the plants, but when any one species had sufficient growth to allow for cutting, this was carried out. However if any one treatment of a particular species was to be cut, the plants of all the other treatments of that species were cut at the same time, irrespective of the amount of growth on the other plants. As far as possible any species was left till all the treatments had reasonable growth for cutting but this was not always possible, especially in cases where the growth from one treatment was so inferior to that of the other treatments that the better growing plants would have been in an advanced stage and cutting might have caused them harm. At times, even when growth was ready for cutting, this was delayed by weather conditions, as no plants were cut when soaked with rain.

2. Method of Cutting.

The cutting of all plants was done with special pairs of shearing blades that were fitted with metal sides welded on the backs of each blade, so that any herbage cut was retained on the actual blades and none was lost before weighing.



In most cases the plant to be cut could be held in the left hand while being cut with the right and all the herbage then retained in the hand till placed on the scales for weighing, but if any growth was too short to allow this to be done, the cut material was retained on the shears till removed for weighing.

3. Weighing the Herbage.

All herbage after cutting was weighed to obtain a "Green weight", dried, then weighed again to give a "Dry weight". These weighings were usually carried out on a set of "Avery" scales that were sensative to approximately 0.2 grams. However if the material was under approximately 20 grams the weighing was carried out on a chemical balance used for weighing grass samples, and that was accurate to at least 0.001 grams. In recording these weights the figures were expressed to the nearest 0.1 gram.

On certain occasions if the weather was especially calm the scales were taken outside to the pots, and the cut herbage weighed immediately, but more usually trays from the drying oven were taken out and the cut material put into a compartment containing a card with the identifying number of the plant on it. When all of one set were cut the trays were taken inside and weighed and the weight recorded on the card.

4. Drying Herbage.

Owing to the fact that so many different plant species were being dealt with, and even different strains of one species, it was decided that "Green weights" might not be a sound basis for comparison, and that "Oven dry weights" would be more reliable. These were also considered necessary, because any lower yielding treatments might have a higher percentage dry matter than higher yielding ones, and green weights would then give an unfair comparison. Most of the drying was done in a specially designed electric drying oven fitted with a thermostat, but at times a special gas heated drying oven was used. However, after cutting, herbage from all treatments of one pasture strain was dried in the same oven, but even if this had not been possible, it was found by placing similar material in each oven that the same dry matter figure was obtained in each case. In these ovens, complete drying of any sample under approximately [illegible] grams took place in under 24 hours, and even if left in the ovens a further 24 hours no further loss in weight took place. After thorough drying, the herbage was weighed again and the weight recorded on the card under a special heading alongside the green weight. The cards for recording were kept as follows:-

<u>TREATMENT V.</u>

Plant No. 4.

Plant Letter.	Date Cut.	Green Wt. Grams.	Dry Wt. Grams.
A	[illegible]	37.0	11.0
B	10.5.47	104.0	[illegible]
C	12.5.47	25.0	[illegible]
etc.			

When one set of weighings was completed all cards were brought together and the details copied into a special record book kept for the purpose.

VII CHEMICAL TESTS CONDUCTED.

The samples of soil extracted from the heaps after mixing all the pots of each treatment (Section V. 1.), were tested in order to find the content of certain essential nutrients in the various treatments. All results are expressed on the basis of oven dry weight.

1. Total Bases.

The soil bases were displaced by the "Ammonium acetate" method (Schollenberger and Dreibelbis, 1930), and the "Total bases" then determined on the leachate by the method of Bray and Willhite (1929).

Treatments.	Total Bases. (m.g equivs. per 100g. soil).
N	17.35
S	14.93
M	12.41
V	6.96
X	2.83

These figures follow the expected trend, showing that in the treatments with stronger acids, Hydrogen-ions have replaced more of the bases which have been removed in the subsequent leaching.

2. Phosphate Studies.

It was considered possible that phosphate was one of the important nutrients liable to cause growth differences at the varying levels of acidity, so a number of different tests were carried out in an attempt to get a picture of the phosphate availability in the different treatments.

(a). The acid soluble phosphorous was measured by the following means:-

(i) The method of Burd & Murphy (1939). In this, 5 gram samples of soil were shaken for 24 hours with 25 C.C.s of .01 N. HCL.

The pH values of the equilibrium suspensions were measured and the differences between these values and those of the original soils show that these soils possess moderate buffering ability.

Soil Treatment.	pH Value of Equilibrium Suspension.	Acid Soluble Phosphate M.gs PO_4 100 grams Soil.
N	5.60	7.6
S	5.22	8.5
M	4.77	8.1
V	3.80	4.9
X	2.95	2.8

These acid soluble figures definitely suggest a considerably lower phosphate availability in the "V" and "X" treatments. Comparing these results with the classification of Burd & Murphy, all these treatments fall in the "intermediate" phosphate level, but "N", "S" and "M" are getting near to the "high", and the "X" treatment is towards the "low" level.

(ii) By employing a variation of the difference principle proposed by Bray & Kurty (1945). In the method used the total of acid soluble plus adsorbed phosphate was found by one gram of soil being shaken for 30 minutes with 50 c.c.s of .01 N HCL. After this time 1 gram of solid NH_4F is added and shaking continued a further hour. The "acid soluble" figure was then obtained by subtracting from this value the amount of adsorbed phosphate as extracted by neutral .5 N NH_4F.

Soil Treatment.	Acid Soluble and Adsorbed Phosphate	Adsorbed.	Acid Soluble Phosphate. M.g. PO_4 per 100 grams soil.
N	87	30	57
S	87	33	54
M	88	33	55
V	86	33	53
X	86	46	40

These figures do not show much variation over the whole range of acidity except that the "X" treatment is significantly lower than

Unpublished work by Fife, suggests that this method is subject to a fundamental error, and too much importance cannot be attached to these figures, especially where the test is on acid soils like "V" and "X", as the resultant figure is too high.

(iii) Direct determination, by shaking 1 gram of soil with 50 C.C.S of .01 N HCL for 30 minutes.

Soil Treatment.	Acid Soluble Phosphate m.g PO_4 per 100 grams soil.
N	53
S	54
M	47
V	39
X	22

The actual figures for "N" and "S" by this method are comparable with those found by the difference principle, (see ii above) while it is noticeable that the "M" figure is slightly lower and the "V" and "X" much lower. This bears out the possiblity mentioned earlier that the figures for extraction by the difference method are probably too high in the case of the more acid soils.

(b) Adsorbed phosphate was measured by the method of Bray and Kurtz (1945), in which 1 gram of ammonium saturated soil* is shaken with 50 C.C.S of .5 N, neutral ammonium fluoride and the phosphate determined on the extract after filtering.

Soil Treatment.	Adsorbed Phosphate m.g. $P.O._4$ per 100 grams soil.
N	30
S	33
M	33
V	33
X	46

The ammonium chloride leachate was also tested for phosphatic content, and the following are the results:-

* Soil leached with 5 C.C.S of neutral, normal NH_4CL.

Soil Treatment.	Phosphate in NH_4 Cl Leachate m.g. PO_4
N	7
S	6
M	4
V	2
X	1

These latter figures particularly suggest that there is greater amount of readily available phosphate in the soil in the less acid range, and that the amount decreases with increasing soil acidity.

(c) These figures on the phosphate availability indicate that under the more acid conditions the phosphate may either be transferred to more insoluble forms not so readily extracted by reagents, or else that some has actually been lost during the original acidification treatments. It would appear however, that the strength of reagents used should extract all phosphate intended to be measured, so that the possibility of the former is not very great.

The results above indicate that in all treatments there should be sufficient phosphate for plant growth, and there is no indication that availability is greater in the more acid treatments. Thus it can fairly safely be said that any growth increase noticed in the more acid soils is not due to a phosphate response.

3. <u>Soil Reaction.</u>

The Hydrogen-ion concentration of the different treatments was measured at the start of the experiment, at the close, and also mid-way between these times. These tests were all carried out using a glass electrode and were conducted by members of the staff of the Plant Chemistry Laboratory, D.S.I.R. The following are the results of the tests at the beginning of the experiment:-

Treatment.	Reaction as pH Units.
N	7.2
S	6.75
M	5.95
V	4.5
X	3.6

Tests were repeated on the same soil kept dry in jars after a few months, and no measurable differences from the above resulted.

(b) Soil After Six Months.

To obtain this test, a large number of plants in each series were tipped from the pots without disturbing the soil, a sample taken and the plant and soil simply replaced in the pot. These samples were bulked and mixed, except that soil from the grasses was kept separate from that from the clovers.

Treatment.	Reaction as pH Units. Grass Pots.	Clover Pots.
N	7.2	7.0
S	6.8	6.75
M	6.0	6.1
V	4.9	4.7
X	4.0	3.7

(c) Soil After One Year, at Close of Experiment.

Treatment.	Reaction as pH Units. Grass Pots.	Clover Pots.
N	7.2	6.3
S	6.7	6.0
M	6.5	5.5
V	5.7	4.9
X	4.4	4.4

To obtain samples for these tests, all the soil from clovers or grasses in any treatment was thoroughly mixed - sampled and tested.

As the pH figures resulting from the clover series were unexpected, soils were remixed, resampled and retested but no major deviation from the above figures resulted.

The following gives a summary of the reactions of both the grass and the clover soils at the three different points in the experiment.

Soil Acidity in pH Units.

Grass Pots.

At Commencement.	After Six Months.	After Twelve Months.
7.2	7.2	7.2
6.75	6.8	6.7
5.95	6.0	6.5
4.5	4.9	5.7
3.6	4.0	4.4

Clover Pots.

At Commencement.	After Six Months.	After Twelve Months.
7.2	7.0	6.3
6.75	6.75	6.0
5.95	6.1	5.5
4.5	4.7	4.9
3.6	3.7	4.4

In the above results the very marked decrease in the acidity of the "N", "S" and "M" clover treatments is totally unexpected. No reference to a similar occurrence has been discovered in the literature perused, but it is of moment that from both the acid and neutral sides the pH has moved towards a point approximately pH 5, which might be the ideal level of acidity for clover plants. Tests were however made only after soil from white and red clovers was mixed so that no clear statement can be made. It is of interest however, that in the case of white clover in this experiment the maximum growth has resulted in the "M" and "V" treatments, which had original pH's of 5.95

and 4.5 and final pH's of 5.3 and 4.9.

4. Herbage Analysis.

It was planned to have a series of analyses done on the herbage material after drying, but owing to the sickness of the chemist concerned, the only test done at the present date is one to find the percentage of ash in the herbage of the Italian ryegrass, Series "J". This was done only on material from the first cut taken on 5th September, 1946, when the dried herbage was ground and ignited in a furnace. The following are the results:-

Treatment.	Ash as % of Dry Matter.
N	7.79
S	7.73
M	7.94
V	9.58
X	9.27

It will be noticed that there is a striking difference between the first three treatments and the last two. It is to be regretted that the ash was not analysed to find which particular minerals had caused this marked increase of ash in the more acid treatments. However, it was observed that the ash from the most acid treatments did not have the red brown indication of large amounts of iron oxides, as reported by Mann (1937).
As mentioned, it is planned to have detailed analyses done of dried herbage from the last cutting of the plants, but these results are not available at the time of writing.

VIII. CONDITION AT END OF EXPERIMENT.

1. Soil.

As stated in the previous section, the acidities of the different treatments at the close of the experiment were not the same as those at the start of the trial. Also the final pH levels for the soils containing grasses differed from those containing clovers.

As far as soil texture is concerned all the treatments appeared to be the same as when planting took place and on removing soil and plants from the pots, the soil could be shaken off the grass roots. In fact this operation was carried out with the plants in order to allow the roots to be weighed. Bates (1934), records that washing soil from roots is not as efficient as rubbing it off when dry, so owing to the fact that the soil used in the experiment was quite free and open, this method was used. In the case of white clover, the roots broke up very easily, and could not be separated from the soil.

2. Plants.

As will be seen from the weighing data (Section IV), all the grasses were fairly dormant at the close of the experiment as the growth over the last six months was very low in all treatments of all species. With the clovers on the other hand, most of the plants were growing quite actively except for one plant, G.X.2, that had died of virus, and a few others which appeared to be more or less affected.

It was decided to weigh the plant roots to see if soil treatments had had any marked effect on the growth of these, and photographs were taken also in order to demonstrate the root formations. Plants and soil were tipped out of the pots on to trays and the soil carefully crushed away to leave the roots free. These were then dipped in a bucket of water, air dried, photographed and weighed. In the case of white clover it was found impossible to get the soil separated from the roots as the latter broke so readily that the attempt had to be abandoned.

In the case of the clovers, nodulation of the plants in the different treatments was compared. It was found that in treatments "N", "S" and "M" for both red and white clovers, the roots had a medium number of very small round nodules, while in treatments "V" and "X" numbers were at least as great if not greater, and the size of nodules was much increased. Many nodules in these latter treatments especially in the case of red clover, had developed into almost "hand" shaped, thus:-  One of the extra large nodules is shown in the "X" treatment of the "H" series at the end of the pointer coming into the picture near the top left hand corner.

IX DATA.

1. PLANT YIELDS. All Yields recorded, are expressed in grams.

A

Perennial Ryegrass, Type. 1.

	27th Sept. '46 Green Weight	27th Sept. '46 Dry Weight	7th Nov. '46 Green Weight	7th Nov. '46 Dry Weight	16th Dec. '46 Green Weight	16th Dec. '46 Dry Weight	6th Feb. '47 Green Weight	6th Feb. '47 Dry Weight
N								
1.	10	3.0	7.5	2.5	6.5	1.9		
2.	8	2.0	9.0	2.5	4.5	1.6		
3.	12	3.0	8.5	2.5	5.5	1.6		
4.	7	2.0	7.0	2.0	3.0	1.1		
5.	9	2.5	7.0	2.5	5.0	1.4		
6.	9	2.5	7.0	2.5	5.0	1.6		
Av.	9.17	2.5	7.7	2.4	4.9	1.5	2.5	.8
S								
1.	12	3.5	10.5	3.0	6.0	1.9		
2.	13	3.0	10.0	3.0	6.5	2.0		
3.	13	3.5	9.0	2.5	6.0	1.9		
4.	7	1.5	5.0	1.5	3.0	1.0		
5.	11	4.0	7.0	2.0	5.0	1.4		
6.	8	1.5	5.0	1.5	3.0	1.2		
Av.	10.6	2.9	7.7	2.3	4.9	1.6	2.2	.7
M								
1.	5	1.5	6.5	1.5	4.0	1.6		
2.	8	1.5	8.5	2.5	4.5	1.6		
3.	9	2.5	7.0	2.0	4.5	1.8		
4.	8	1.5	6.0	1.5	4.5	1.5		
5.	8	1.5	7.0	2.0	4.5	1.7		
6.	14	4.0	10.0	3.5	3.0	1.2		
Av.	8.7	2.1	7.5	2.2	4.2	1.6	2.7	1
V								
1.	10	2.5	8.5	2.5	7.5	1.9		
2.	15	4.5	8.0	2.0	5.0	1.6		
3.	11	2.5	6.5	1.5	4.0	1.3		
4.	12	3.5	7.5	2.0	5.0	1.6		
5.	9	3.0	7.0	2.0	6.0	1.9		
6.	8	2.5	7.5	2.0	4.0	1.4		
Av.	10.9	3.1	7.5	2.0	5.3	1.6	2.3	.8
X								
1.	11	3.0	7.0	2.5	5.0	1.8		
2.	10	2.5	10.0	3.0	5.0	1.8		
3.	10	2.5	7.5	2.0	6.0	1.6		
4.	9	2.5	9.5	2.5	6.0	1.8		
5.	9	2.5	5.5	1.5	4.0	1.3		
6.	14	4.0	7.5	2.5	8.0	2.1		
Av.	10.5	2.9	7.8	2.3	5.7	1.7	2.2	.7

A

Perennial Ryegrass, Type. 1. (Cont'd).

N

	23rd June '47 Green Weight	Dry Weight	Total Mean Green Weight	Dry Weight
1.	8.0	2.1		
2.	5.0	1.7		
3.	5.0	1.6		
4.	5.0	1.6		
5.	4.5	1.4		
6.	5.5	1.6		
Av.	5.5	1.7	29.8	8.9

S

1.	4.0	1.5		
2.	4.0	1.3		
3.	5.0	1.7		
4.	4.0	1.4		
5.	2.0	1.0		
6.	4.5	1.5		
Av.	3.9	1.4	29.3	8.9

M

1.	4.0	1.6		
2.	4.0	1.7		
3.	5.5	1.8		
4.	5.0	1.7		
5.	5.5	2.0		
6.	4.0	2.0		
Av.	4.7	1.8	27.8	8.7

V

1.	4.5	1.8		
2.	4.5	1.7		
3.	4.0	1.6		
4.	4.5	1.8		
5.	4.5	1.6		
6.	5.5	1.8		
Av.	4.6	1.7	30.6	9.2

X

1.	3.5	1.3		
2.	3.5	1.1		
3.	2.0	1.0		
4.	3.5	1.5		
5.	3.0	1.4		
6.	2.0	1.1		
Av.	2.9	1.2	29.1	8.8

B

Perennial Ryegrass, Type. 3.

N

	30th Sept. '46 Green Weight	30th Sept. '46 Dry Weight	11th Nov. '46 Green Weight	11th Nov. '46 Dry Weight	17th Dec. '46 Green Weight	17th Dec. '46 Dry Weight	6th Feb. '47 Green Weight	6th Feb. '47 Dry Weigh
1.	7.0	2.0	5.5	2.0	2.0	1.1		
2.	11	3.5	8.5	3.0	3.5	1.4		
3.	6.5	1.5	6.0	2.0	3.5	1.3		
4.	7.5	3.0	2.0	.5	3.0	.9		
5.	12	4.0	7.0	2.5	1.5	.8		
Av.	8.8	2.8	5.8	2.0	2.7	1.1	3.4	1.4

S

	30th Sept. '46 Green Weight	30th Sept. '46 Dry Weight	11th Nov. '46 Green Weight	11th Nov. '46 Dry Weight	17th Dec. '46 Green Weight	17th Dec. '46 Dry Weight	6th Feb. '47 Green Weight	6th Feb. '47 Dry Weigh
1.	14.5	4.0	9.0	3.0	2.5	1.3		
2.	8	2.5	5.5	2.5	2.5	1.1		
3.	24	7.0	11.5	3.5	3.5	1.3		
4.	9	2.5	6.5	2.0	2.0	1.0		
5.	10.0	2.0	5.0	1.2	2.0	1.0		
Av.	13.1	3.6	7.5	2.4	2.5	1.2	2.0	1.0

M

	30th Sept. '46 Green Weight	30th Sept. '46 Dry Weight	11th Nov. '46 Green Weight	11th Nov. '46 Dry Weight	17th Dec. '46 Green Weight	17th Dec. '46 Dry Weight	6th Feb. '47 Green Weight	6th Feb. '47 Dry Weigh
1.	18	5.5	8.5	3.0	3.0	1.3		
2.	11	3.5	7.5	2.5	3.0	1.0		
3.	7	1.5	6.0	2.0	3.5	1.4		
4.	30	9.0	14.0	5.5	4.5	1.8		
5.	7	2.0	7.0	2.0	3.5	1.4		
Av.	14.6	4.3	6.8	3.0	3.5	1.4	4.2	1.6

V

	30th Sept. '46 Green Weight	30th Sept. '46 Dry Weight	11th Nov. '46 Green Weight	11th Nov. '46 Dry Weight	17th Dec. '46 Green Weight	17th Dec. '46 Dry Weight	6th Feb. '47 Green Weight	6th Feb. '47 Dry Weigh
1.	12	3.5	10.0	3.0	4.0	1.2		
2.	17.5	5.5	6.0	3.0	3.0	1.2		
3.	19.5	6.0	11.5	3.5	3.0	1.2		
4.	19.0	6.0	10.5	3.0	3.0	1.2		
5.	16	5.0	8.5	2.5	3.0	1.0		
Av.	16.8	5.2	9.3	3.0	3.2	1.2	2.2	1.0

X

	30th Sept. '46 Green Weight	30th Sept. '46 Dry Weight	11th Nov. '46 Green Weight	11th Nov. '46 Dry Weight	17th Dec. '46 Green Weight	17th Dec. '46 Dry Weight	6th Feb. '47 Green Weight	6th Feb. '47 Dry Weigh
1.	12	3.5	8.5	3.0	2.0	.9		
2.	5.5	1.5	3.5	.5	2.0	.5		
3.	12	4.0	7.0	2.0	1.0	.7		
4.	9	2.5	6.0	1.5	1.5	.9		
5.	11.5	2.5	7.0	2.5	2.0	.8		
Av.	10	2.8	6.4	2.0	1.7	.8	2.2	1.0

B

Perennial Ryegrass. Type. 3. (Cont'd).

N

	23rd June '47 Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	4.7	.4		
2.	1.0	.7		
3.	2.0	.7		
4.	3.5	1.5		
5.	2.0	.7		
Av.	2.6	.8	23.3	8.1

S

	Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	1.5	.8		
2.	.4	.3		
3.	.5	.3		
4.	1.0	.6		
5.	1.5	.6		
Av.	1.0	.7	26.1	8.9

M

	Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	2.0	.8		
2.	3.5	1.3		
3.	2.5	1.4		
4.	3.0	1.9		
5.	2.5	1.7		
Av.	2.7	1.3	31.8	11.6

V

	Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	2.1	.9		
2.	3.3	1.3		
3.	3.2	1.2		
4.	3.1	1.2		
5.	1.8	.8		
Av.	2.7	1.1	34.2	11.5

X

	Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	2.7	1.3		
2.	2.5	1.1		
3.	2.0	1.0		
4.	.8	.6		
5.	1.2	.7		
Av.	1.8	.9	22.1	7.5

C

Italian Ryegrass

N

	5th Sept. '46 Green Weight	5th Sept. '46 Dry Weight	14th Oct. '46 Green Weight	14th Oct. '46 Dry Weight	13th Nov. '46 Green Weight	13th Nov. '46 Dry Weight	17th Dec. '46 Green Weight	17th Dec. '46 Dry Weigh
1.	41	10	19	5.0	6.5	1.5	10.0	2.8
2.	50	11	15	3.5	3.0	.5	.5	.3
3.	38	8	13	3.0	5.0	1.0	10.0	3.0
4.	54	11	17	4.5	5.0	1.0	7.5	2.2
5.	40	8	12	2.5	5.0	1.0	7.0	2.2
Av.	44.6	9.6	15.2	3.7	4.9	1.0	7.0	2.1

S

	5th Sept. '46 Green Weight	5th Sept. '46 Dry Weight	14th Oct. '46 Green Weight	14th Oct. '46 Dry Weight	13th Nov. '46 Green Weight	13th Nov. '46 Dry Weight	17th Dec. '46 Green Weight	17th Dec. '46 Dry Weigh
1.	54	12	18	5.0	9.0	3.0	10.5	3.1
2.	50	11	19	4.5	10.0	3.0	10.5	3.3
3.	47	10	13	3.5	6.5	2.0	7.5	2.2
4.	51	11	16	3.5	8.0	2.0	9.0	2.6
5.	39	8	12	3.5	5.5	1.5	7.5	2.2
Av.	48.2	10.4	15.4	4.0	7.6	2.3	9.0	2.7

M

	5th Sept. '46 Green Weight	5th Sept. '46 Dry Weight	14th Oct. '46 Green Weight	14th Oct. '46 Dry Weight	13th Nov. '46 Green Weight	13th Nov. '46 Dry Weight	17th Dec. '46 Green Weight	17th Dec. '46 Dry Weigh
1.	52	13	19	5.0	8.0	2.5	9.5	2.7
2.	69	15	17	5.5	5.0	1.0	4.5	1.1
3.	77	17	18	4.5	5.0	1.0	2.0	.8
4.	29	8	10	2.0	2.0	.5	1.5	.9
5.	46	10	16	4.0	8.0	2.5	6.0	1.9
Av.	54.6	12.6	16	4.2	5.6	1.5	4.7	1.5

V

	5th Sept. '46 Green Weight	5th Sept. '46 Dry Weight	14th Oct. '46 Green Weight	14th Oct. '46 Dry Weight	13th Nov. '46 Green Weight	13th Nov. '46 Dry Weight	17th Dec. '46 Green Weight	17th Dec. '46 Dry Weigh
1.	38	9	15	4.0	6.5	1.5	6.0	2.0
2.	60	13	23	6.0	8.0	2.0	8.0	2.4
3.	31	7	13	3.5	5.5	1.0	5.5	1.8
4.	74	15	25	6.7	9.0	3.0	8.0	2.4
5.	51	10	20	5.5	5.5	3.0	2.5	.9
Av.	50.8	10.8	19.2	5.2	6.9	2.1	6.0	1.9

X

	5th Sept. '46 Green Weight	5th Sept. '46 Dry Weight	14th Oct. '46 Green Weight	14th Oct. '46 Dry Weight	13th Nov. '46 Green Weight	13th Nov. '46 Dry Weight	17th Dec. '46 Green Weight	17th Dec. '46 Dry Weigh
1.	39	9	16	3.5	7.5	2.0	9.5	2.7
2.	52	12	21	4.5	8.0	2.0	9.0	2.7
3.	20	5	10	2.0	4.0	1.0	5.0	1.6
4.	25	5	13	3.5	6.0	1.5	6.5	2.0
5.	44	10	17	2.5	6.0	1.5	7.5	2.2
Av.	36	8.2	15.6	3.2	6.3	1.6	7.5	2.2

C

Italian Ryegrass (Cont'd).

N

	6th Feb. '47 Green Weight	Dry Weight	25th June '47 Green Weight	Dry Weight	Total Mean Green Weight	Dry Weight
1.			2.0	1.1		
2.			4.1	1.4		
3.			.8	.5		
4.			1.4	.7		
5.			2.7	1.6		
Av.	5.6	1.6	2.2	1.1	79.5	19.1

S

1.			1.1	.8		
2.			2.6	1.2		
3.			3.6	1.4		
4.			3.1	1.4		
5.			3.4	1.6		
Av.	6.2	2.0	2.8	1.3	89.2	22.7

M

1.			4.4	1.4		
2.			3.7	1.2		
3.			4.5	1.3		
4.			4.5	1.4		
5.			12.8	2.8		
Av.	5.0	1.4	6.0	1.6	91.9	22.8

V

1.			4.3	1.6		
2.			5.6	2.5		
3.			4.2	1.6		
4.			8.2	2.2		
5.			4.2	1.8		
Av.	5.6	2.0	5.3	1.9	93.8	23.9

X

1.			2.9	1.3		
2.			3.0	1.3		
3.			3.9	1.7		
4.			9.2	2.5		
5.			3.6	1.5		
Av.	5.8	2.0	4.5	1.7	75.7	18.9

D

Short Rotation Ryegrass.

N

	11th Sept. '46 Green Weight	Dry Weight	15th Oct. '46 Green Weight	Dry Weight	13th Nov. '46 Green Weight	Dry Weight	19th Dec. '46 Green Weight	Dry Weight
1.	27	6	10.0	2.7	4.0	1.0	5.5	1.8
2.	15	3	5.0	1.6	.5	.3	.5	.3
3.	40	11	11.0	3.1	5.0	1.5	2.5	1.0
4.	19	5	9.5	2.6	5.0	1.5	9.0	2.7
5.	15	4	7.0	1.9	5.0	1.0	7.0	2.3
Av.	23.2	5.8	8.5	2.4	3.9	1.0	4.9	1.6

S

	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight
1.	27	7	8.0	2.4	4.0	1.0	3.0	1.2
2.	22	4	8.0	2.3	4.0	1.0	7.5	2.2
3.	34	9	15.0	4.0	5.5	1.5	8.0	2.5
4.	29	7	9.0	2.6	5.5	1.5	5.5	1.8
5.	27	7	12.0	3.2	5.0	1.5	8.5	2.3
Av.	27.8	6.8	10.4	2.9	4.8	1.3	6.5	2.0

M

	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight
1.	16	3	8.0	2.3	4.5	1.0	7.0	1.9
2.	24	5	11.0	2.9	5.5	1.5	7.0	2.1
3.	15	3	7.0	2.0	5.0	1.5	7.0	1.9
4.	23	5	10.5	2.9	4.5	1.0	3.5	1.2
5.	15	4	6.0	1.7	5.0	1.5	9.5	2.7
Av.	18.6	4.0	8.5	2.3	4.9	1.3	6.8	2.0

V

	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight
1.	20	5	7.5	2.1	3.0	.5	6.0	1.5
2.	26	7	7.5	2.2	3.5	.5	5.0	1.5
3.	20	4	7.0	2.2	4.0	1.0	5.5	1.6
4.	34	8	10.0	2.7	5.5	1.5	6.5	2.0
5.	29	8	10.5	2.9	4.5	1.0	9.0	2.6
Av.	25.8	6.4	8.5	2.4	4.3	.9	6.4	1.8

X

	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight
1.	18	4	6.0	1.5	4.0	1.0	5.0	1.8
2.	23	6	7.0	1.7	3.0	.5	6.5	2.1
3.	27	7	9.5	2.5	3.0	.5	6.5	2.2
4.	26	6	8.5	2.1	6.0	1.5	7.0	2.1
5.	27	7	11.0	2.9	3.5	.5	7.5	2.3
AV.	24.2	6.0	8.4	2.1	3.9	.8	6.5	2.1

D

Short Rotation Ryegrass (Cont'd).

	6th Feb. '47 Green Weight	6th Feb. '47 Dry Weight	25th June '47 Green Weight	25th June '47 Dry Weight	Total Green Weight	Mean Dry Weight
N						
1.	7		6.7	1.5		
2.	5		6.9	2.3		
3.	4		4.9	1.9		
4.	7		6.0	2.2		
5.	7		6.1	2.1		
Av.	6.0	1.4	6.1	2.0	52.6	14.2
S						
1.	3		5.0	1.6		
2.	6		6.7	2.2		
3.	6		7.3	2.6		
4.	5		6.3	2.1		
5.	6		7.7	2.4		
Av.	5.2	1.6	6.6	2.2	61.3	16.8
M						
1.	6		6.0	1.6		
2.	3		5.7	1.4		
3.	7		4.8	1.4		
4.	3		6.6	1.5		
5.	5		5.1	1.6		
Av.	4.8	1.2	5.6	1.5	49.2	12.3
V						
1.	5		5.6	1.6		
2.	4		5.1	2.5		
3.	5		4.3	1.2		
4.	5		4.1	1.3		
5.	7		3.4	1.4		
Av.	5.2	1.5	4.5	1.6	54.7	14.6
X						
1.	4		2.8	1.2		
2.	6		2.6	1.0		
3.	5		2.1	.9		
4.	4		2.5	1.1		
5.	5		3.1	1.3		
Av.	4.8	1.2	2.2	1.1	50.0	13.3

E

Cocksfoot Selected

	10th Oct. '46 Green Weight	10th Oct. '46 Dry Weight	19th Nov. '46 Green Weight	19th Nov. '46 Dry Weight	18th Dec. '46 Green Weight	18th Dec. '46 Dry Weight	6th Feb. '47 Green Weight	6th Feb. '47 Dry Weigh
N								
1.	9.5		4.0	1.0	1.0	.5	5	
2.	9.0		2.5	1.0	4.5	1.3	5	
3.	6.5		2.5	.5	3.0	1.1	5	
4.	7.0		3.5	1.0	3.5	.9	6	
5.	7.0		4.5	1.0	2.0	.7	6	
Av.	7.4	2.5	3.2	.9	2.5	.9	5.4	1.3
S								
1.	8.0		4.0	1.0	3.5	1.0	4	
2.	4.5		2.0	1.0	2.0	.8	4	
3.	6.5		2.0	1.0	2.0	.6	4	
4.	5.5		2.0	.5	2.5	.7	4	
5.	5.5		2.5	1.0	2.0	.6	5	
Av.	6.0	2.0	2.5	.9	2.4	.7	4.2	1.0
M								
1.	7.0		4.5	1.3	3.0	.9	5	
2.	5.0		2.5	.8	2.0	.7	5	
3.	8.5		2.5	.8	4.0	1.0	5	
4.	14.0		6.0	1.7	3.0	.9	5	
5.	11.0		5.0	1.2	3.5	.9	6	
Av.	9.3	3.1	4.1	1.1	3.1	.9	5.2	1.2
V								
1.	6.0		2.0	.7	1.5	.5	4	
2.	8.0		4.0	1.2	3.0	.9	4	
3.	10.5		4.0	1.3	3.5	1.2	5	
4.	8.0		3.5	1.0	2.0	.6	5	
5.	9.5		4.5	1.3	3.5	1.0	6	
Av.	8.5	2.6	3.6	1.3	2.7	.8	4.8	1.1
X								
1.	9.0		5.0	1.3	2.0	.5	5	
2.	8.5		5.5	1.5	3.0	.9	3	
3.	8.0		4.5	1.4	3.0	1.1	3	
4.	10.0		4.5	1.5	1.5	.4	4	
5.	8.5		5.0	1.3	3.5	.9	4	
Av.	8.6	2.8	4.9	1.4	2.6	.8	3.8	1.0

E

Cocksfoot Selected (Cont'd).

N

	25th June '47 Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	3.1	1.0		
2.	3.6	1.4		
3.	3.9	1.4		
4.	4.6	1.5		
5.	3.5	1.3		
Av.	3.7	1.3	22.2	6.9

S

	Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	4.2	1.4		
2.	3.4	1.1		
3.	4.2	1.1		
4.	3.7	1.1		
5.	5.3	1.6		
Av.	4.2	1.3	19.3	5.9

M

	Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	4.1	1.4		
2.	4.5	1.5		
3.	4.0	1.4		
4.	5.2	1.7		
5.	4.5	1.7		
Av.	4.5	1.6	26.2	7.9

V

	Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	3.2	1.2		
2.	4.3	1.4		
3.	3.3	1.4		
4.	3.4	1.3		
5.	3.6	1.3		
Av.	3.6	1.3	23.2	7.3

X

	Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	2.7	1.1		
2.	3.3	1.2		
3.	4.1	1.6		
4.	3.8	1.3		
5.	3.4	1.5		
Av.	3.5	1.3	23.4	7.3

F

Cocksfoot Danish

N

	10th Oct. '46 Green Weight	Dry Weight	21st Nov. '46 Green Weight	Dry Weight	18th Dec. '46 Green Weight	Dry Weight	6th Feb. '47 Green Weight	Dry Weight
1.	3.0		2.0	.7	4.5	1.1	4	
2.	4.5		4.0	1.1	5.5	1.5	4	
3.	2.0		2.0	.7	4.0	1.2	4	
4.	3.5		3.5	.9	4.0	1.1	4	
5.	3.5		1.5	.7	3.5	.9	5	
Av.	3.3	1.1	2.6	.8	4.3	1.2	4.2	1.6

S

1.	3.0		2.0	.6	3.5	1.0	4	
2.	2.0		2.0	.6	5.0	1.2	4	
3.	2.0		2.0	.6	6.5	1.5	5	
4.	3.5		2.0	.6	5.5	1.2	4	
5.	2.5		2.0	.6	4.0	1.1	3	
Av.	2.6	.8	2.0	.6	4.9	1.2	4	1.2

M

1.	5.0		3.0	.9	4.5	1.3	4	
2.	5.0		3.5	.9	3.0	1.2	4	
3.	2.0		3.0	.9	6.0	1.5	4	
4.	5.0		3.0	.8	2.0	.7	3	
5.	5.0		3.0	.9	3.0	.9	4	
Av.	4.4	1.5	3.1	.9	3.7	1.1	3.8	1.1

V

1.	5.0		4.0	1.1	2.0	.6	4	
2.	4.0		2.0	.5	1.5	.6	3	
3.	5.0		3.0	.9	3.5	.7	3	
4.	4.0		3.5	1.1	1.5	.6	3	
5.	4.0		3.5	1.0	3.0	.8	3	
Av.	4.4	1.5	3.2	.9	2.3	.7	3.2	1.0

X

1.	8.0		6.0	1.7	2.0	.8	4	
2.	8.0		5.0	1.5	2.5	.8	3	
3.	5.5		4.0	1.1	5.5	1.4	3	
4.	4.0		3.0	.7	2.5	.8	2	
5.	3.5		2.0	.6	2.5	.8	2	
Av.	5.8	1.9	4.0	1.1	3.0	.9	2.8	1.1

F

Cocksfoot Danish (Cont'd).

N

	25th June '47 Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	3.9	1.7		
2.	5.5	2.0		
3.	4.0	1.5		
4.	7.0	2.3		
5.	5.1	1.7		
Av.	5.1	1.8	19.5	6.5

S

	Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	4.3	1.4		
2.	4.1	1.4		
3.	4.5	1.7		
4.	4.2	1.4		
5.	2.6	.5		
Av.	3.9	1.3	18.5	5.2

M

	Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	3.4	1.3		
2.	4.8	1.7		
3.	4.5	1.5		
4.	3.7	1.2		
5.	3.6	1.4		
Av.	4.0	1.4	19.0	6.0

V

	Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	3.8	1.4		
2.	3.3	1.1		
3.	4.4	1.5		
4.	3.5	1.3		
5.	4.0	1.5		
Av.	3.8	1.4	16.9	5.5

X

	Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	3.2	1.3		
2.	3.1	1.3		
3.	2.8	1.2		
4.	2.7	1.1		
5.	2.9	1.1		
Av.	2.9	1.2	18.5	6.2

G

Broad Red Clover

N

	3rd Feb. '47 Green Weight	Dry Weight	5th March '47 Green Weight	Dry Weight	29th May '47 Green Weight	Dry Weight	Total Mean Green Weight	Dry Weight
1.	163.0	43.0	20	3.0	52	10.5		
2.	116.0	26.0	28	5.5	42	9.0		
3.	108.5	25.0	16	3.5	23	6.0		
4.	111.0	26.0	20	4.0	79	16.0		
5.	108.5	24.0	37	8.0	55	12.5		
Av.	121.4	28.8	24.2	4.8	50.0	10.8	195.8	44.4

S

1.	133.0	33	17	3.5	27	8.5		
2.	107.0	23	20	4.0	50.5	12.5		
3.	119.0	29	34	7.0	64	16.0		
4.	120.0	27	25	5.5	47	12.5		
5.	80.5	20	14	3.0	33.5	7.5		
Av.	111.9	26.4	22	4.6	44.4	11.4	178.0	42.4

M

1.	100	24	25.0	5.5	43	10.5		
2.	116	32	40	8.0	82	20.5		
3.	118	31	26	5.0	15	5.0		
4.	134	34	40	5.5	64	15.0		
5.	127	33	30	6.0	72	17.5		
Av.	119	30.8	32.2	6.0	55.2	13.7	206.0	50.5

V

1.	133	35	32	7.0	83	19		
2.	84	20	27	5.0	62	14		
3.	96	23	22	4.0	80	15		
4.	95	20	26	5.0	68	13.5		
5.	74	20	31	7.0	65	15.0		
Av.	96.4	23.6	27.6	5.6	71.6	15.3	196.0	44.5

X

1.	41	12	8.0	1.5	8.0	1.0		
2.	51	14	15.0	3.5	Dead.	Virus.		
3.	60	17	14	2.5	20.0	5.0		
4.	64	19	11	2.0	25.0	5.0		
5.	75	21	21	5.0	26	5.0		
Av.	58.2	16.6	13.8	2.9	19.8	4.0	92.0	23.5

H

Montgomery red clover

	7th Nov. '46 Green Weight	Dry Weight	8th Jan. '47 Green Weight	Dry Weight	5th March '47 Green Weight	Dry Weight	29th May '47 Green Weight	Dry Weight
N								
1.	38.0	8.5	199.0	50.0	71	18.5	65.0	16.5
2.	34.0	8.0	232.0	57.0	75	17.0	64.0	15.0
3.	27.0	6.0	247.0	59.0	71	16.5	60.5	15.5
4.	30.5	6.5	151.0	36.0	35	9.0	46.5	10.5
5.	43.0	9.0	181.0	43.0	41	10.0	49.0	11.0
Av.	34.5	7.6	202.0	49.0	58.6	14.2	57.0	13.7
S								
1.	43.0	9.5	273.0	65.0	67	18.0	60.5	18.0
2.	49.0	10.5	329.0	70.0	58	20.5	59	17.0
3.	53.0	11.0	347.0	72.0	73	18.0	57	16.5
4.	66.0	13.5	432.0	96.0	97	21.5	67	19.5
5.	37.5	8.0	305.0	63.0	116	26.0	60	16.5
Av.	49.7	10.5	337.0	73.0	82.2	20.8	60.7	17.5
M								
1.	77.5	15.0	347.0	80.0	93	29.0	66	18
2.	53.5	11.0	321.0	66.0	85	27.0	63	16
3.	61.5	12.0	235.0	45.0	62	18.5	69	18
4.	68.0	15.5	414.0	85.0	91	21.0	55	15.5
5.	30.0	6.5	315.0	74.0	101	23.5	57	18
Av.	58.1	12.0	332.0	70.0	86.4	23.8	62.0	17.1
V								
1.	40.5	9.0	239.0	50.0	44	14.0	38.0	9.5
2.	21.0	4.5	260.0	60.0	40	16.0	29.0	8.0
3.	17.0	3.0	208.0	41.0	32	10.0	31.0	8.0
4.	12.0	3.0	263.0	59.0	87	21.0	77.0	19.0
5.	32.0	7.0	322.0	66.0	85	22.0	61.0	15.0
Av.	24.5	5.3	258.0	55.0	57.6	16.6	47.2	11.9
X								
1.	24.0	6.0	64.0	20.0	40	13.0	22.0	4.0
2.	13.0	4.0	34.0	10.0	24	9.0	19.0	5.0
3.	No Growth		39.0	11.0	29	9.0	15.0	3.5
4.	" "		49.0	15.0	54	17.0	1.5	.3
5.	" "		28.0	8.0	34	10.0	9.5	1.5
Av.	7.4	2.0	43.0	13.0	36.2	11.6	13.4	2.9

H

Montgomery red clover (Cont'd).

N

	Total Green Weight	Mean Dry Weight
1.		
2.		
3.		
4.		
5.		
Av.	352.0	84.5

S

	Total Green Weight	Mean Dry Weight
1.		
2.		
3.		
4.		
5.		
Av.	530.0	122.0

M

	Total Green Weight	Mean Dry Weight
1.		
2.		
3.		
4.		
5.		
Av.	539.0	123.0

V

	Total Green Weight	Mean Dry Weight
1.		
2.		
3.		
4.		
5.		
Av.	387.0	89.0

X

	Total Green Weight	Mean Dry Weight
1.		
2.		
3.		
4.		
5.		
Av.	100.0	30.0

I

White Clover Type 1.

N

	17th Oct. '46 Green Weight	17th Oct. '46 Dry Weight	11th Nov. '46 Green Weight	11th Nov. '46 Dry Weight	7th Jan. '47 Green Weight	7th Jan. '47 Dry Weight	10th March '47 Green Weight	10th March '47 Dry Weight
1.	22.0	4.5	18.0	3.5	63.0	16.0	33.0	10.0
2.	34.0	6.0	19.5	4.0	78.0	18.0	29.0	10.0
3.	24.0	5.0	16.0	3.5	52.5	14.5	37.0	11.0
4.	24.0	4.5	16.5	3.5	58.0	16.0	44.0	13.0
5.	29.0	6.0	29.5	6.5	62.0	17.5	50	12.0
Av.	26.2	5.2	20.3	4.2	62.7	16.4	38.6	11.2

S

	17th Oct. '46 Green Weight	17th Oct. '46 Dry Weight	11th Nov. '46 Green Weight	11th Nov. '46 Dry Weight	7th Jan. '47 Green Weight	7th Jan. '47 Dry Weight	10th March '47 Green Weight	10th March '47 Dry Weight
1.	21.5	5.0	22.0	5.5	112.5	23.5	63.0	19.0
2.	11.0	2.0	15.5	4.5	111.0	23.0	73.0	20.0
3.	24.5	5.0	26.0	6.5	120.0	26.0	22.0	62.0
4.	29.5	5.5	25.5	6.5	79.0	18.5	82.0	23.0
5.	24.0	5.0	23.0	5.5	98.0	24.5	61.0	18.0
Av.	22.1	4.5	22.4	5.7	104.1	23.1	71.0	20.4

M

	17th Oct. '46 Green Weight	17th Oct. '46 Dry Weight	11th Nov. '46 Green Weight	11th Nov. '46 Dry Weight	7th Jan. '47 Green Weight	7th Jan. '47 Dry Weight	10th March '47 Green Weight	10th March '47 Dry Weight
1.	59.5	11.0	60.0	12.0	155.0	30.5	96.0	24.0
2.	36.0	7.5	37.0	8.5	108.0	22.0	89.0	22.0
3.	26.0	4.5	55.0	11.0	164.0	33.5	138.0	36.0
4.	34.0	6.0	60.0	12.0	127.0	29.0	85.0	22.0
5.	43.0	9.0	64.0	12.5	153.5	36.0	108.0	29.0
Av.	39.7	7.6	59.2	11.0	141.5	30.2	103.2	26.6

V

	17th Oct. '46 Green Weight	17th Oct. '46 Dry Weight	11th Nov. '46 Green Weight	11th Nov. '46 Dry Weight	7th Jan. '47 Green Weight	7th Jan. '47 Dry Weight	10th March '47 Green Weight	10th March '47 Dry Weight
1.	18.0	4.0	45.0	9.5	186.0	37.0	107.0	27.0
2.	16.5	3.5	47.5	9.5	159.0	31.5	100.0	26.0
3.	19.0	4.0	50.0	9.5	170.0	36.5	80.0	21.0
4.	14.5	2.5	53.0	11.0	107.5	23.5	104.0	28.0
5.	33.0	6.5	67.0	13.0	148.0	33.0	108.0	31.0
Av.	20.2	4.1	52.5	10.7	154.1	32.3	97.8	26.6

X

	17th Oct. '46 Green Weight	17th Oct. '46 Dry Weight	11th Nov. '46 Green Weight	11th Nov. '46 Dry Weight	7th Jan. '47 Green Weight	7th Jan. '47 Dry Weight	10th March '47 Green Weight	10th March '47 Dry Weight
1.	34.0	8.0	24.5	5.5	32.0	10.0	7.0	5.0
2.	10.0	2.0	10.5	2.0	45.0	12.5	5.0	2.5
3.	29.5	6.0	20.5	4.5	34.5	10.5	8.0	4.0
4.	19.0	4.0	12.0	2.5	35.5	9.0	10.0	4.5
5.	29.5	6.5	23.5	5.0	46.0	15.5	4.0	2.5
Av.	23.0	5.3	18.2	3.9	38.6	11.5	6.8	3.7

I

White Clover Type 1. (Cont'd).

N

	29th May '47 Green Weight	Dry Weight	Total Green Weight	Mean Dry Weight
1.	30.0	6.0		
2.	30.0	7.0		
3.	25.0	6.0		
4.	30.0	6.5		
5.	35.0	8.5		
Av.	30.0	6.8	178.0	43.8

S

1.	36.0	8.0		
2.	41.0	9.0		
3.	62.0	15.0		
4.	53.5	13.0		
5.	47.0	12.0		
Av.	47.9	11.4	268.0	65.1

M

1.	55.0	13.0		
2.	52.0	12.0		
3.	60.5	14.0		
4.	43.0	9.5		
5.	50.0	12.0		
Av.	52.1	12.1	396.0	87.5

V

1.	71.0	17.0		
2.	70.5	15.0		
3.	67.0	15.0		
4.	74.0	15.0		
5.	70.0	15.5		
Av.	70.5	15.5	395.0	89.2

X

1.	3.0	.5		
2.	1.5	.3		
3.	1.5	.3		
4.	2.0	.5		
5.	2.0	.5		
Av.	2.0	.4	89.0	24.8

K

White Clover. Type II

N

	21st Nov. '46 Green Weight	Dry Weight	19th Dec. '46 Green Weight	Dry Weight	6th Feb. '47 Green Weight	Dry Weight	29th May '47 Green Weight	Dry Weight
1.	12.0	3.7	42.0	10.0	25.0	7.5	10.0	2.0
2.	11.4	3.0	49.5	9.0	25.0	6.5	9.0	2.0
3.	27.3	6.7	70.0	14.0	32.0	8.0	10.5	2.5
4.	36.2	8.7	68.0	12.5	23.0	5.0	7.0	2.0
5.	25.6	6.1	54.5	11.0	29.0	8.5	16.0	4.0
Av.	22.5	5.6	56.8	11.3	26.8	7.1	10.5	2.5

S

	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight
1.	17.7	4.5	69.0	15.0	38.0	9.0	3.0	1.5
2.	32.2	8.0	77.0	18.0	39.0	11.5	5.0	2.0
3.	18.5	4.1	45.5	10.0	40.0	9.0	23.0	5.5
4.	17.4	4.6	52.5	12.0	25.0	7.0	1.0	.3
5.	37.7	9.1	70.5	16.0	35.0	10.0	5.0	2.0
Av.	24.7	6.1	62.9	14.2	35.4	9.3	7.4	2.2

M

	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight
1.	39.1	8.9	84.0	17.0	5.0	12.5	8.0	2.0
2.	26.7	6.3	94.5	19.0	76.0	17.5	7.0	2.0
3.	10.3	2.4	35.0	8.0	28.0	7.5	14.0	3.5
4.	28.7	7.0	54.5	12.0	35.0	7.5	10.0	3.0
5.	6.7	1.9	35.0	9.0	30.0	8.0	6.0	2.0
Av.	22.3	5.3	60.6	13.0	43.8	10.6	9.0	2.5

V

	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight
1.	40.2	9.7	130.5	24.0	81.0	17.0	23.0	5.5
2.	6.1	1.7	40.5	8.0	41.0	10.0	43.5	10.5
3.	41.6	9.9	135.5	26.0	101.0	20.0	20.0	5.0
4.	31.8	7.2	135.5	27.0	113.0	22.0	25.0	7.0
5.	23.3	5.6	41.0	11.0	45.0	11.0	30.0	5.0
Av.	28.6	6.8	88.6	19.2	76.2	16.0	28.3	6.6

X

	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight	Green Weight	Dry Weight
1.	11.7	2.9	43.0	11.0	35.0	11.0	2.0	.5
2.	5.7	1.4	20.5	4.0	18.0	5.0	1.0	.3
3.	7.5	1.9	30.5	7.5	37.0	7.5	15.0	3.5
4.	12.0	2.7	36.0	8.0	33.0	9.0	8.0	1.5
5.	21.5	4.9	44.0	12.0	40.0	11.0	2.0	.5
Av.	11.7	2.7	34.8	8.5	32.6	8.7	5.6	1.2

K

White Clover. Type II. (Cont'd).

N

	Total Green Weight	Mean Dry Weight
1.		
2.		
3.		
4.		
5.		
Av.	117.0	26.5

S

1.		
2.		
3.		
4.		
5.		
Av.	130.0	31.8

M

1.		
2.		
3.		
4.		
5.		
Av.	136.0	31.4

V

1.		
2.		
3.		
4.		
5.		
Av.	222.0	48.6

X

1.		
2.		
3.		
4.		
5.		
Av.	85.0	21.1

PERCENTAGE DRY MATTER.

2. The following are the mean figures for dry matter per cent in each series.

SERIES	TREATMENTS N.	S.	M.	V.	X.	SERIES MEAN
A	29.8	30.4	31.2	30.1	30.2	30.3
B	34.7	34.1	36.5	33.6	33.9	34.5
C	24.0	25.4	24.8	25.4	24.9	24.9
D	26.9	27.4	25.0	26.6	26.6	26.5
E	31.1	30.6	30.1	31.4	31.1	30.8
F	33.3	29.3	31.6	32.5	33.5	32.0
G	22.6	23.8	24.5	22.7	25.5	23.8
H	24.0	23.0	22.8	23.0	30.0	24.5
I	24.6	24.3	22.1	22.6	27.6	24.2
K	22.6	24.5	23.1	21.9	24.8	23.3
Treatment Mean	27.4	27.3	27.2	27.8	28.8	

WEIGHT OF PLANT ROOTS.

3. The following are the average weights of roots from the different treatments of each series, expressed as grams of dry matter.

GRASS ROOTS.

SERIES	TREATMENTS				
	N.	S.	M.	V.	X.
A	23.0	6.7	7.8	7.7	12.7
B	4.8	6.4	4.8	5.2	7.0
C	5.4	7.0	5.0	14.8	14.0
D	8.6	9.6	8.8	9.8	7.4
E	5.1	3.3	10.0	7.4	11.0
F	4.3	3.4	4.0	4.0	8.6
Total	51.7	36.4	40.4	48.9	60.7
Mean	8.6	6.1	6.7	8.1	10.1

CLOVER ROOTS.

SERIES	TREATMENTS				
	N.	S.	M.	V.	X.
G	52.0	24.6	38.5	14.4	12.1
H	52.4	44.8	26.8	15.6	10.5
Total	104.4	69.4	65.3	30.0	22.6
Mean	52.2	34.7	32.6	15.0	11.3

FLOWERING OF WHITE CLOVER SERIES

4. A. FLOWERING OF SERIES "I"

REPLICATIONS	TREATMENTS				
	N.	S.	M.	V.	X.
I1	93	103	78	86	89
I2	102	91	95	91	88
I3	91	91	71	78	108
I4	101	83	93	55	74
I5	97	107	124	84	101
Total	484	475	461	394	460
Mean	97	95	92	79	92

B FLOWERING OF SERIES "K"

REPLICATIONS	TREATMENTS				
	N.	S.	M.	V.	X.
K1	89	85	97	94	98
K2	94	99	96	102	96
K3	69	85	87	111	104
K4	94	101	92	89	119
K5	80	101	125	109	100
Total	426	471	497	506	517
Mean	85.2	94.2	99.4	101.2	103.4

X

ANALYSIS OF DATA.

The analyses in this section were conducted under the guidance of Mr. I.D. Dick, Officer in charge, Biometric Section, Department of S. & I.R. who approved of methods used and decisions made.

For convenience, when dealing with yields of the treatments in each series, a table is given with a summary of the total yields of each plant and the mean of all replications. The figures given, express the total yields of each plant as grams of dry matter.

SERIES "A"

PERENNIAL RYEGRASS, TYPE I.

Total Plant yields, as grams of dry matter.

REPLICATIONS	TREATMENTS				
Plant Numbers	N.	S.	M.	V.	X.
A.1	9.5	9.9	6.2	8.7	8.6
A.2	7.8	9.3	7.3	9.8	8.4
A.3	8.7	9.6	8.1	6.9	7.1
A.4	6.7	5.4	6.2	8.9	8.3
A.5	7.8	8.4	7.2	8.5	6.7
A.6	8.2	5.7	10.7	7.7	9.6
Bulked Cut 6th Feb. '47	4.8	4.2	6.0	4.8	4.2
Mean	8.9	8.9	8.7	9.2	8.2

The figures for the cut on 6.2.47 when bulked weights only were recorded are included to give the final mean.

It will be seen that the means of the different treatments are so similar that there is no point in subjecting these results to statistical analysis. Thus in the case of Type 1 Perennial ryegrass the different levels of soil acidity have had no effect in altering the plant yields.

SERIES "B"

PERENNIAL RYEGRASS, TYPE III.

Total Plant yields, as grams of dry matter.

REPLICATIONS	TREATMENTS				
Plant Numbers	N.	S.	M.	V.	X.
B.1	5.5	9.1	10.6	8.1	8.7
B.2	8.6	6.4	8.3	11.0	3.6
B.3	5.5	12.1	6.3	11.9	7.7
B.4	5.9	6.1	18.2	11.4	5.5
B.5	8.0	4.8	7.1	9.3	6.5
Total	33.5	38.5	50.5	51.7	32.0
Mean	6.7	7.7	10.1	10.3	6.4

N.B. - The cut on 6.2.47 when only bulked weights were taken is omitted for purposes of the following analyses.

TABLE

	df	S.S.	M.S.	F.
Treatments	4	69.60	17.40	1.112 N.S.
Error	20	313.07	15.65	
Total	24	382.67		

The expected value for "F" is 2.87 at 5% point so differences in this series are not significant.

However seeing that the greatest variation in replications is found in treatments "S" and "M" these are omitted in the following analysis:-

	df	S.S.	M.S.	F.
Treatments	2	48.10	24.05	8.125 S.S.
Error	12	35.56	2.96	
Total	14	83.66		

Differences of 2.37 between means significant at 5%.

" " 3.31 " " " " 1%.

Thus we see that when "S" and "M" are omitted differences between "V" yields and those of "N" and "X" are highly significant.

SERIES "C"

ITALIAN RYEGRASS

Total Plant yields, as grams of dry matter.

REPLICATIONS			TREATMENTS		
Plant Numbers	N.	S.	M.	V.	X.
C.1	20.4	23.9	24.6	18.1	18.5
C.2	18.2	22.5	23.8	25.5	22.4
C.3	15.5	19.1	24.6	14.9	11.3
C.4	19.5	20.5	12.8	30.3	14.5
C.5	15.3	17.3	21.2	21.2	18.2
Bulked cut 6th Feb. '47	8.0	10.0	7.0	10.0	10.0
Mean	19.1	22.7	22.8	23.9	18.9

N.B. The cut on 6.2.47 when bulked weights only were recorded is included to give the final mean.

	df	S.S	M.S.	F.
Treatments	4	101.2	25.3	1.41 N.S.
Error	20	357.9	17.9	
Total	24	469.1		

Tabular "F" for the above analysis is 2.87 at the 5% point, so differences between means in this series are not significant.

SERIES "D"

SHORT ROTATION RYEGRASS.

Total Plant yields, as grams of dry matter.

REPLICATIONS	TREATMENTS				
Plant Numbers	N.	S.	M.	V.	X.
D.1	13.0	13.2	9.8	10.7	9.5
D.2.	7.5	11.7	12.9	13.7	11.3
D.3	18.5	19.6	9.8	10.0	13.1
D.4	14.0	15.0	11.6	15.5	12.8
D.5	11.3	16.4	11.5	15.9	14.0
Bulked cut 6th Feb. '47	7.0	8.0	6.0	7.5	6.0
Mean	14.2	16.8	12.3	14.6	13.3

N.B. The cut on 6.2.47 when bulked weights only were recorded, is included to give the true mean.

From these figures it is obvious that there are no significant differences between means of any of the treatments in this series.

SERIES "E"

COCKSFOOT - SELECTED

Total Plant yields, as grams of dry matter.

REPLICATIONS	TREATMENTS				
Plant Numbers	N.	S.	M.	V.	X.
E.1	2.5	3.4	3.5	2.5	2.9
E.2	3.7	2.9	3.0	3.5	3.6
E.3	3.0	2.7	3.2	3.9	4.1
E.4	3.4	2.3	4.3	2.9	3.2
E.5	3.0	3.2	3.8	3.6	3.7
Bulked cuts 10th Oct. '46 & 6th Feb. '47	19.0	15.0	21.5	19.5	19.0
Mean	6.9	5.9	7.9	7.3	7.3

The cuts on 10.10.46 and 6.2.47 when bulked weights only were recorded, are included here to give the final mean.

From an examination of the above figures, it is obvious that there are no significant differences between means of any of the treatments in this series.

SERIES "F"

COCKSFOOT - DANISH

Total Plant yields, as grams of dry matter.

REPLICATIONS	TREATMENTS				
Plant Numbers	N.	S.	M.	V.	X.
F.1	3.5	3.0	3.5	3.1	3.8
F.2	4.6	3.2	3.8	2.2	3.6
F.3	3.4	3.8	3.9	3.1	3.7
F.4	4.3	3.2	2.7	3.0	2.6
F.5	3.3	2.2	3.2	3.3	2.5
Bulked cuts 10th Oct. '46 6th Feb. '47	13.5	10.0	13.0	12.5	15.0
Mean	6.5	5.2	6.0	5.5	6.2

The yields of the cuts taken on 1.10.46 and 6.2.47 when only bulked weights were recorded are included to give the final mean.

From an examination of the above figures, it is obvious that there are no significant differences between yields of any of the treatments in this series.

SERIES "G"

BROAD RED CLOVER.

Total Plant yields, as grams of dry matter.

REPLICATIONS	TREATMENTS				
Plant Numbers	N.	S.	M.	V.	X.
G.1	56.5	45.0	40.0	61.0	14.5
G.2	40.5	39.5	60.5	39.0	17.5
G.3	34.5	52.0	41.0	42.0	24.5
G.4	46.5	45.0	54.5	38.0	26.0
G.5	44.5	30.5	56.5	42.0	31.0
Mean	44.5	42.4	50.5	44.5	23.5

In this case it was considered the "X" treatment was so obviously significantly lower that it was not included in further analysis.

TABLE

	df	S.S.	M.S.	
Treatments	3	183.04	61.01	
Error	16	1123.20	70.20	N.S.
Total	19	1406.24		

In this analysis, seeing the error Mean Square is greater than the treatment Mean Square, there are no significant differences between the yields of treatments "N", "S", "M" and "V".

Thus the only significant difference in this series, is that the "X" treatment is lower than all the others.

SERIES "H"

MONTGOMERY RED CLOVER.

Total Plant yields, as grams of dry matter.

REPLICATIONS	TREATMENTS				
Plant numbers	N.	S.	M.	V.	X.
H.1	93.5	110.5	142.0	82.5	43.0
H.2	97.0	118.5	120.0	88.5	28.0
H.3	97.0	117.5	93.5	62.0	23.5
H.4	62.0	150.5	137.0	102.0	32.3
H.5	73.0	113.5	121.5	110.0	19.5
Mean	84.5	122.0	123.0	89.0	29.3

In the following analysis the "X" treatment has been omitted because it is so obviously lower in yield than any other treatment.

	df	S.S.	M.S.	F.
Treatments	3	6424.3	2141.43	7.14 S.S
Error	16	4801.0	300.06	
Total	19	11225.3		

Differences of 23.1 between means significant at 5%

" " 31.9 " " " " 1%

From the above we can say that the "X" yields are significantly lower than any other. Differences between "N" yields and "V" yields are not significant, nor are those between "S" and "M". However the differences between yields of "N" or "V" and "S" or "M" are highly significant.

SERIES "I"

WHITE CLOVER, TYPE I

Total Plant yields, as grams of dry matter.

REPLICATIONS	TREATMENTS				
Plant Numbers	N.	S.	M.	V.	X.
I.1	40.0	61.0	90.5	94.5	29.0
I.2	45.0	38.5	72.0	85.5	19.3
I.3	40.0	74.5	99.0	86.0	25.3
I.4	43.5	66.5	78.5	80.0	20.5
I.5	50.5	65.0	98.5	99.0	30.0
Mean	43.8	65.1	87.5	89.2	24.8

Here too, the differences between "X" yields and those of all the others are so obviously significant that "X" figures have been omitted from the following analysis.

TABLE

	df	S.S.	M.S.	F.
Treatments	3	6884.5	2294.8	38.9 S.S.
Error	16	941.8	58.86	
Total	19	7826.3		

Difference of 10.0 between means significant at 5%

" " 13.9 " " " " 1%

Thus in the means above, differences between "M" and "V" are not significant but all other differences are highly significant. That is, "M" and "V" are better than "N", "S" and "X", "S" better than "N" and "X" and "N" better than "X".

SERIES "K"

WHITE CLOVER, TYPE II.

Total Plant weights, as grams of dry matter

REPLICATIONS	TREATMENTS				
Plant Numbers	N.	S.	M.	V.	X.
K.1	23.2	30.0	40.4	56.2	25.4
K.2	20.5	39.5	44.8	30.2	10.7
K.3	31.2	28.6	21.4	60.9	20.4
K.4	28.2	23.9	29.5	63.2	21.2
K.5	29.6	37.1	20.9	32.6	28.4
Mean	26.5	31.8	31.4	48.6	21.1

	df	S.S.	M.S.	F.
Treatments	4	2113.02	528.26	5.51 S.S.
Error	20	1916.30	95.82	
Total	24	4029.32		

Differences of 13 between means significant at 5% level

" " 18 " " " " 1% "

Thus the differences between "V" treatment and "N" or "X" are highly significant, while those between "V" and "S" or "M" are just significant. There is no significance in any differences between yields of "N", "S", "M" and "X" treatments.

FLOWERING OF SERIES "I"

Numbeр of flowers per plant

Plant Numbers	TREATMENTS				
	N.	S.	M.	V.	X.
I.1	93	103	78	86	89
I.2	102	91	95	91	88
I.3	91	91	71	78	108
I.4	101	83	93	55	74
I.5	97	107	124	84	101
Mean	97	95	92	79	92

ANALYSIS OF THE ABOVE FIGURES

	df	S.S.	M.S.	F.
Treatments	4	993	248	1.298 N.S.
Error	20	3822	191	
Total	24	4815		

Tabular F = 2.87 @ 5% level, so no significance can be attached to any differences between means in the above results.

FLOWERING OF SERIES "K"

Number of flowers per plant.

	TREATMENTS				
Plant Number	N.	S.	M.	V.	X.
K.1	89	85	97	94	98
K.2	94	99	96	102	96
K.3	69	85	87	111	104
K.4	94	101	92	89	119
K.5	80	101	125	109	100
Mean	85.2	94.2	99.4	101.2	103.4

ANALYSIS OF ABOVE FIGURES

	df	S.S.	M.S.	F.	
Treatments	4	1247	311.7	2.94	S.
Error	20	2120	106.0		
Total	24	3367			

Tabular F = 2.87 at 5% level, so certain means in the above treatments are significant.

Difference of 13.6 between means significant at 5%.

Thus the mean of treatment "N" is significantly lower than those of treatments "M", "V" and "X".

XI. RESULTS.

Series "A". Perennial Ryegrass, Type I.

This series of plants, in common with the other grasses used, grew well at the beginning of this experiment but growth soon slumped and production was actually very poor over most of the time the measurements were taken.

The mean yields of replications in treatments at each cut, expressed on a "Dry weight" basis, are as follows:-

Mean Yields of Perennial Ryegrass
Type I.

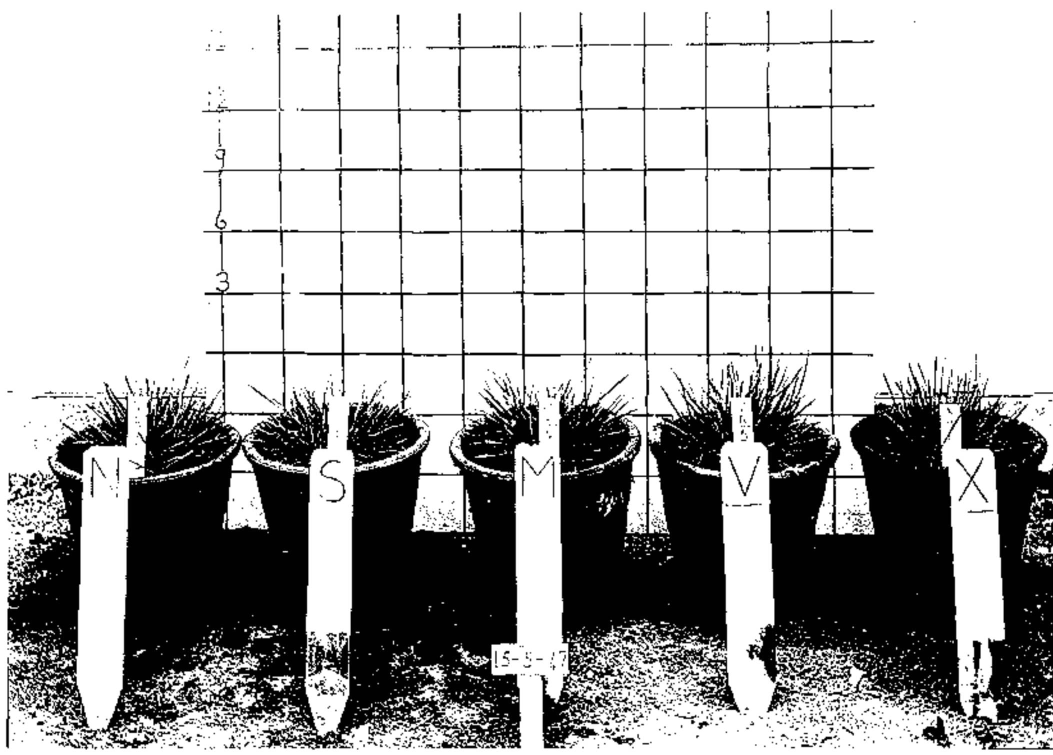
Grams of Dry Matter Per Cut.

Cutting Dates.	Treatments.				
	N	S	M	V	X
27th Sept. '46	2.5	2.9	2.1	3.1	2.9
7th Nov. '46	2.4	2.3	2.2	2.0	2.3
16th Dec. '46	1.5	1.6	1.6	1.6	1.7
6th Feb. '47	0.8	0.7	1.0	0.8	0.7
23rd June, '47	1.7	1.4	1.8	1.7	1.2
Treatment Totals.	8.9	8.9	8.7	9.2	8.8

The most remarkable fact about these plants, is that at any cut a number of plants in each treatment yielded exactly the same weight of herbage, and but for an odd plant yielding much more or less than the average, it would appear that mean yields might have been even more alike than they actually are. However from an examination of mean yields it is obvious that the plants have not reacted to the different levels of acidity with different weights of herbage.

Thus in this type of Perennial ryegrass, the different levels of soil reaction have had no effect in altering the plant yields.

The following photograph shows an average plant from each of the treatments in this series, as it was at the close of the experiment. The herbage on these plants represents 14 weeks' growth.



The type of roots on the plants in each treatment of this series can be seen in the following photograph.

It can be observed that the root form is different in some of the treatments, and from this photograph and the weights recorded it is seen that the roots in treatment "N" were very much heavier than in any other, with the "X" treatment also higher than the remainder.

Treatment.	Average Root Weight as Grams Dry Matter.
N	23.0
S	6.7
M	7.8
V	7.7
X	12.7

The percentage dry matter in the herbage from the plants of this series showed only small variations, the following being the mean figures.

Treatment.	% D.M.
N	29.8
S	30.4
M	31.2
V	30.1
X	30.2

Series "B". Perennial Ryegrass Type III.

The plant selected for this series was one that had been under observation for twelve months and had been found characteristic of the type to be represented. Usually the production is less than that of Type I Perennial ryegrass, and the plants are very liable to rust badly in the early autumn.

The mean yields of replications in treatments at each cut, expressed on a dry weight basis, are as follows:-

Mean Yields of Perennial Ryegrass
Type III.

Grams of Dry Matter Per Cut.

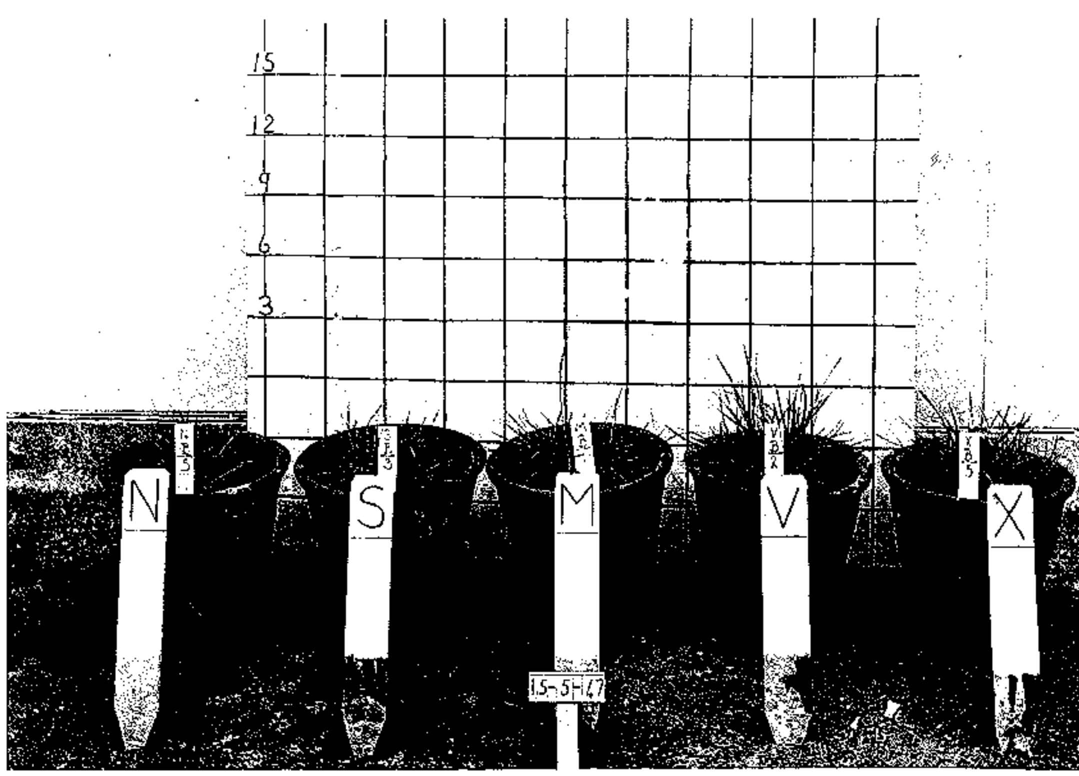
Cutting Dates.	Treatments.				
	N	S	M	V	X
30th Sept. '46	2.8	3.6	4.3	5.2	2.8
11th Nov. '46	2.0	2.4	3.0	3.0	2.0
17th Dec. '46	1.1	1.2	1.4	1.2	0.8
6th Feb. '46	1.4	1.0	1.6	1.0	1.0
23rd June '46	0.8	0.7	1.3	1.1	0.9
Treatment Totals.	8.1	8.9	11.6	11.5	7.5

The yields of this plant under the different treatments are rather interesting, as both "M" and "V" mean yields are higher than those of any Type I treatments. Also it will be seen in the detail of yields at the different cuts, that when the weights of herbage from the first two cuts of series "A" and "B" are considered, the total average yield of "B" is higher than that of "A" in all but treatment "N". Also at this time the highest plant yield in series "B" decline quickly and more than half the final total yield of each treatment was recorded in the first five months of the experiment.

As shown in section X, the differences between the mean yields of treatments "N" or "X", and "V", are highly significant, so that the yield at pH [illegible].9 is truly greater than that at 7.2 or 4.0. This fact is clearly brought out especially in the results of the first two cuts when the plants were growing actively. At that time average yields of "X" and "N" treatments were identical and if this yield is taken as 100, the yield of "S" is 125, "M" is 152 and "V" is 171. At the close of the experiment "M" and "V" were still holding their supremacy despite the fact that actual yields were so small, and that the soil pH had changed considerably.

So it would appear that under conditions ruling in this experiment the most vigorous growth of Type III, Perennial ryegrass was in the "Mediumly acid" to "Very acid" soils.

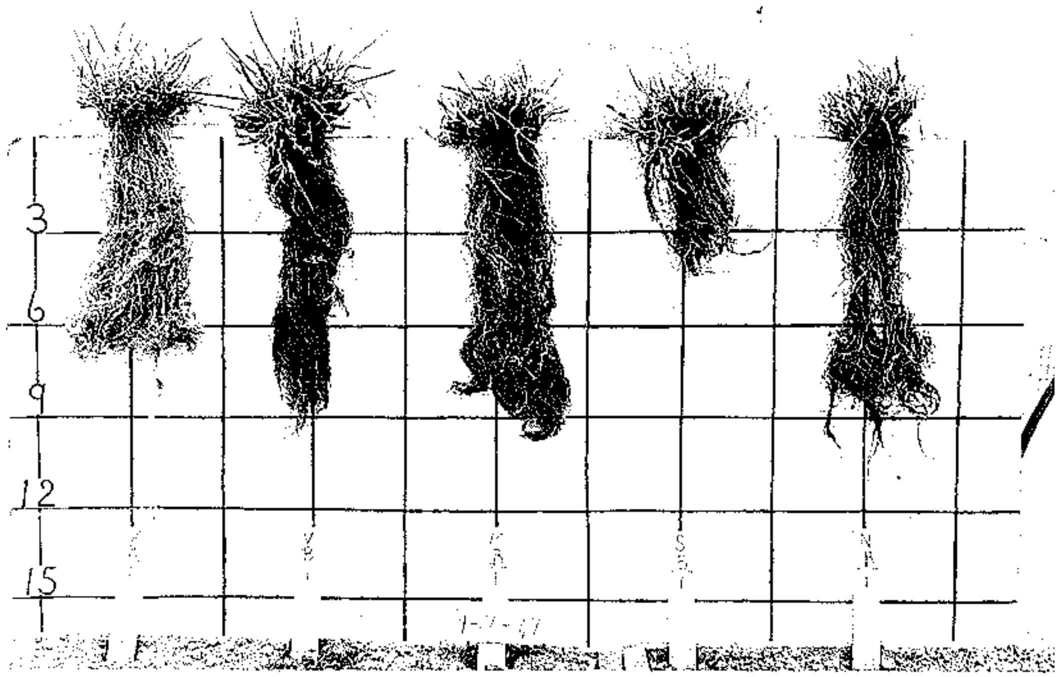
The following shows an average plant from each treatment at the close of the present experiment:-



Figures for percentage dry matter in the herbage of this series are as follows:-

Treatment.	% D.M.
N	34.7
S	34.1
M	36.5
V	33.6
X	33.9

A sample of the plant roots in each treatment are shown in the next photograph. It should be stated that the roots of plants from treatments "S" all had a fault or weakness at one place in their length and so none were obtained with their full length intact.



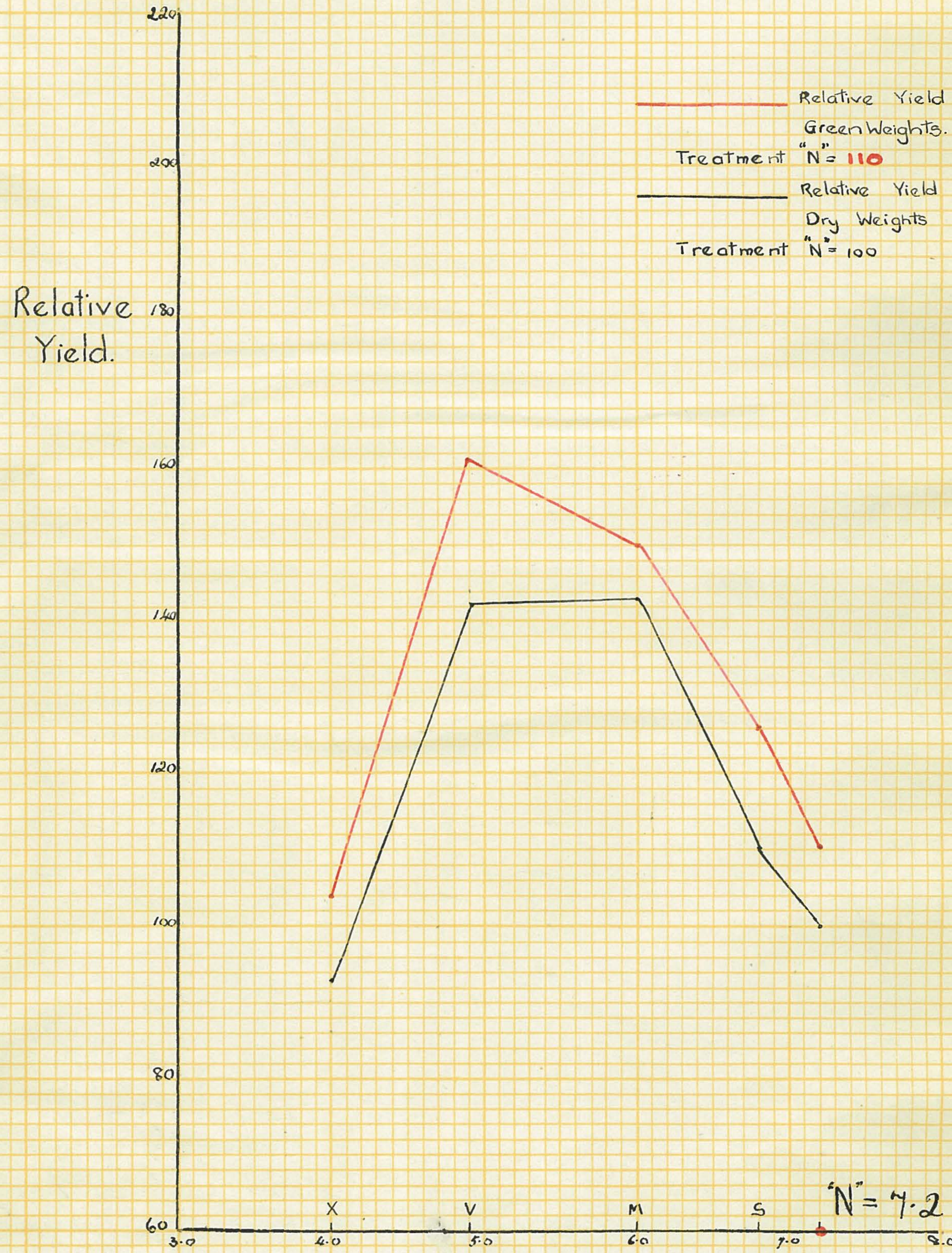
Average root weights were as follows:-

Treatments.	Root Weights Grams Dry Matter.
N	4.8
S	6.4
M	4.8
V	5.2
X	7.0

The graph on the following page compares the relative yields of the treatment in this series, and at the same time illustrates changes in percentage dry matter in the various treatments.

Relative Yields of Perennial Ryegrass, Type 3.

Series "B."



Acidity in pH Units.

Series "C". Italian Ryegrass.

This series is of special interest because of the very quick growth that was made at the beginning of the experiment. In fact in most treatments approximately half the total mean yield of the plants was recorded in less than three months' growth.

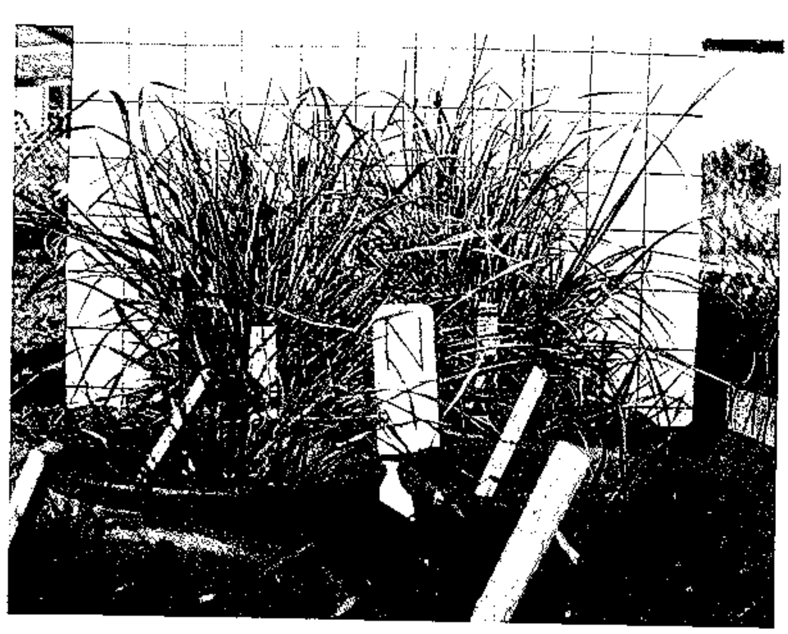
The mean yields of replications in treatments at each cut, expressed on a dry weight basis, are as follows:-

Mean Yields of Italian Ryegrass

Grams of Dry Matter per Cut.

Cutting Dates.	Treatments.				
	N	S	M	V	X
5th Sept. '46	9.6	10.4	12.6	10.8	8.2
14th Oct. '46	3.7	4.0	4.2	5.2	3.2
13th Nov. '46	1.0	2.3	1.5	2.1	1.6
17th Dec. '46	2.1	2.7	1.5	1.9	2.2
6th Feb. '47	1.6	2.0	1.4	2.0	2.0
25th June '47	1.1	1.3	1.6	1.9	1.7
Treatment Totals	19.1	22.7	22.8	23.9	18.9

The growth of plants in the different treatments can be seen in the following photographs, taken 4th September, 1946.



Italian rye in Neutral Soil. 4 Sept. 1946.

Italian rye in Slightly acid Soil. 4 Sept. 46.

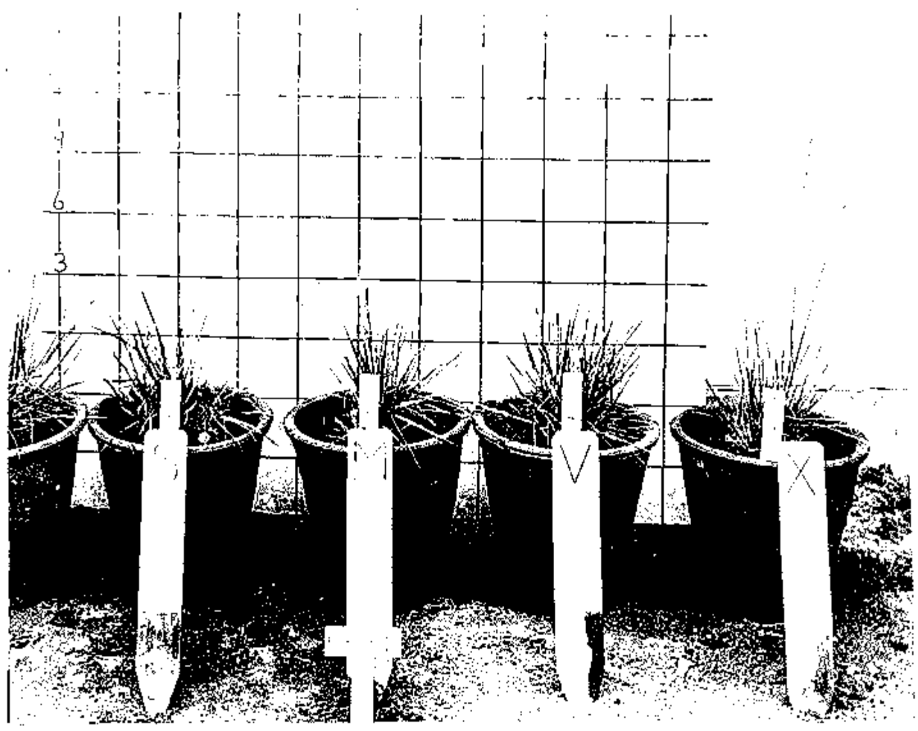
Italian rye in Slightly acid Soil. [illegible] Sept. 46.

Italian rye in Very Acid soil. 4 Sept. 40.

Italian rye in Extremely Acid Soil. 4 Sept. 40.

The yields of treatments in this series show no significant differences, because the variation within treatments is greater than that between treatments, so the only conclusion we can come to is that the level of soil acidity has not influenced the plant yields in the case of this Italian ryegrass.

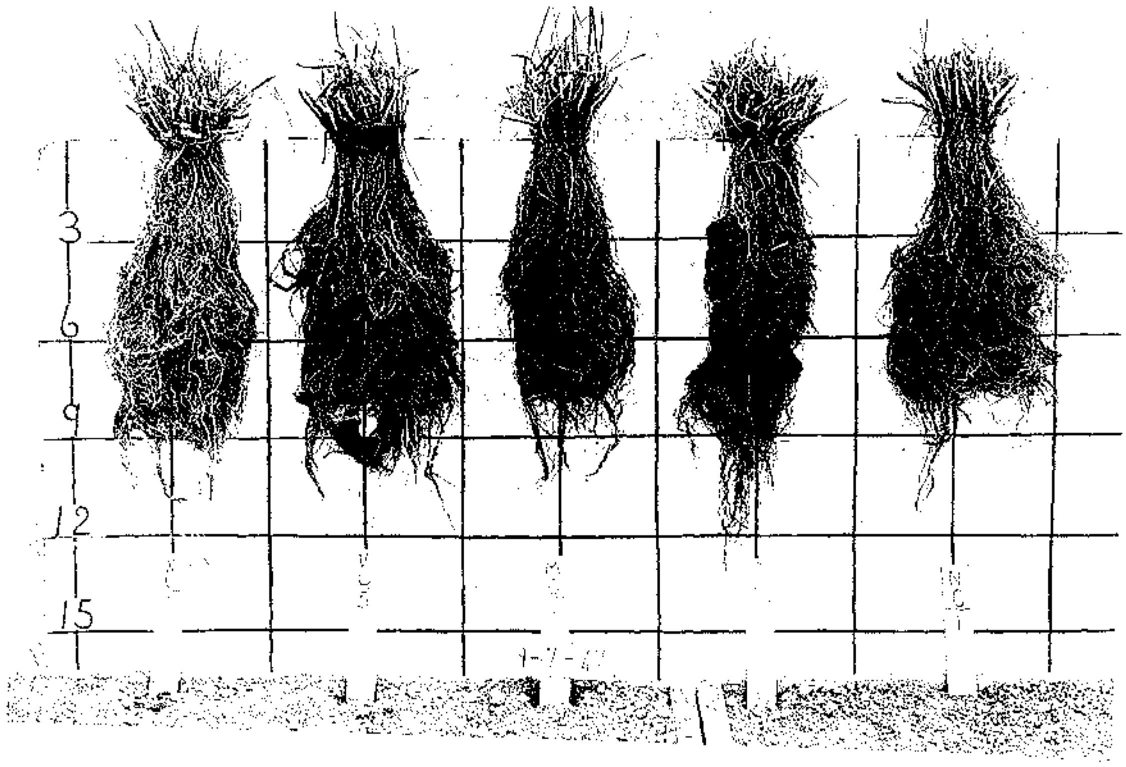
The following photograph shows the plants as at the close of the experiment. It is of interest to compare the position here with that in the previous photographs, in which the herbage represents a shorter growth period.



The average figures for percentage dry matter in the herbage of this series are as follows:-

Treatment.	% D.M.
N	24.0
S	25.0
M	24.8
V	25.4
X	24.9

The type of root system of the plants in the treatments of this series can be seen in the following photograph:-



Mean root weights in this series are as follows:-

Treatment.	Mean Root Weight Grams Dry Matter.
N	5.4
S	7.0
M	5.0
V	14.8
X	14.0

Series "D". Short Rotation Ryegrass.

As in the previous series the variation within treatments is greater than that between treatments, so that there can be no significance attached to any differences between resultant means.

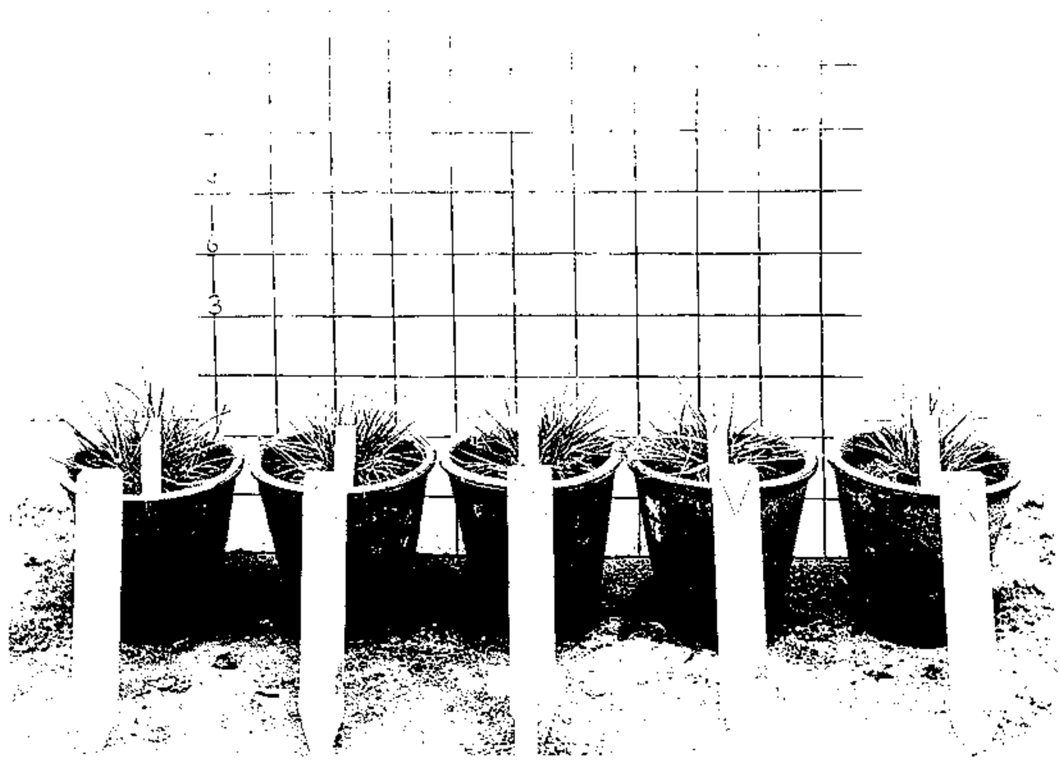
The mean yields of replications in treatments at each cut, expressed on a dry weight basis, are as follows:-

Mean Yields of Short Rotation Ryegrass.

Grams of Dry Matter Per Cut.

Cutting Dates.	Treatments.				
	N	S	M	V	X
11th Sept. '46	5.8	6.8	4.0	6.4	6.0
15th Oct. '46	2.4	2.9	2.3	2.4	2.1
13th Nov. '46	1.0	1.3	1.3	.9	.8
19th Dec. '46	1.6	2.0	2.0	1.8	2.1
6th Feb. '47	1.4	1.6	1.2	1.5	1.2
25th June '47	2.0	2.2	1.5	1.6	1.1
Treatment Totals	14.2	16.8	12.3	14.6	13.3

In this case too, the mean yields at the close of the first four months was more than half the total for twelve months, The following photograph shows samples of the plants as they were at the close of the experiment.



As far as the percentage dry matters are concerned, the following figures show the averages for this series:-

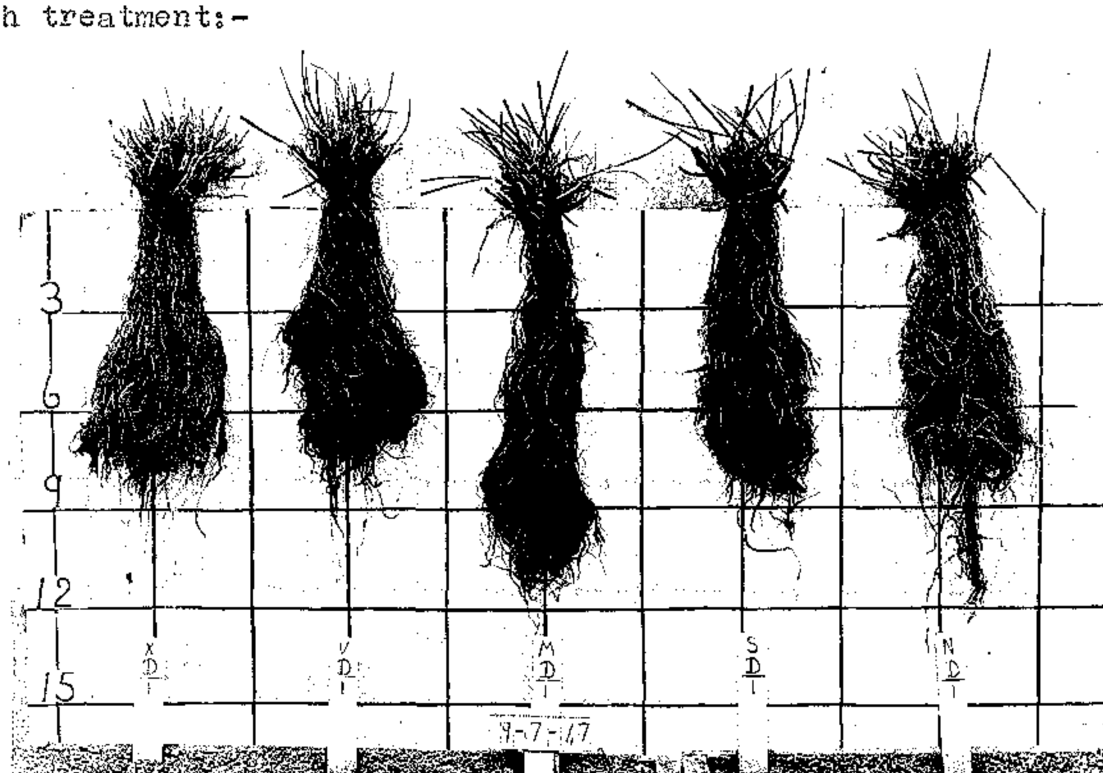
Treatment.	% D.M.
N	26.9
S	27.4
M	25.0
V	26.6
X	26.6

These figures are much lower than those for the Perennial ryegrasses and are nearly as low as those for the Italian ryegrass, so are actually intermediate between the two, but tending to be nearer the Italian than the Perennial.

The average weight of plant roots at the end of the experiment is as follows:-

Treatment.	Average Root Weight. Grams Dry Matter.
N	8.6
S	9.6
M	8.8
V	9.8
X	7.5

The following photograph shows the roots of a characteristic plant of each treatment:-



Series "E". Cocksfoot, Selected.

This series of plants grew very poorly right throughout the experiment and at no time did they thrive. However, what little growth there was, was spread evenly over the whole twelve months of the experiment.

The mean yields of all replications in treatments at each cut, expressed on a dry weight basis, are as follows:-

Mean Yields of Cocksfoot, Selected.

Grams of Dry Matter Per Cut.

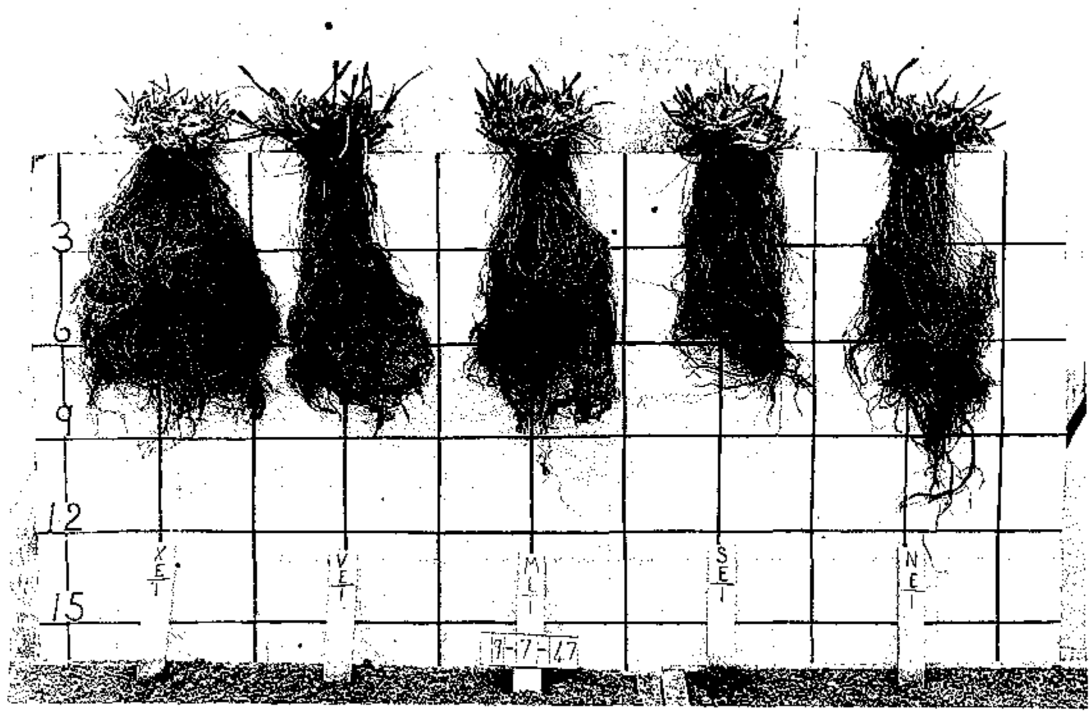
Cutting Dates.	Treatments.				
	N	S	M	V	X
10th Oct. '46	2.5	2.0	3.1	2.8	2.8
19th Nov. '46	.9	.9	1.1	1.3	1.4
18th Dec. '46	.9	.7	.9	.8	.8
6th Feb. '47	1.3	1.0	1.2	1.1	1.0
25th June '47	1.3	1.3	1.6	1.3	1.3
Treatment Totals	6.9	5.9	7.9	7.2	7.3

In two of the five cuts only bulk dry matters were taken, and two of the remaining cuts show considerable variation within the treatments. Thus the figures would be difficult to analyse, and with the degree of variation present in the treatments, it was considered that there could be no statistical significance in any differences between the mean yields.

The following are the average figures for the percentage dry matter of this series:-

Treatment.	% D.M.
N	31.1
S	30.6
M	30.1
V	31.4
X	31.1

The type of roots found on plants in the different treatments is shown in the following photograph.



Of particular interest in this series is the great difference in the root systems of the different treatments, in that those from plants grown in the more acid soils are finer and more fibrous than those from the other treatments.

Average root weights are as follows:-

Treatment.	Average Root Weights. Grams Dry Matter.
N	5.1
S	3.3
M	10.0
V	7.4
X	11.0

Series "F". Cocksfoot, Danish.

The remarks for the previous type of cocksfoot (series E) also apply to the present series. Here too the growth was very poor at all times and production was fairly evenly spread over the whole growth period.

The mean yields of all replications in treatments at each cut, expressed on a dry weight basis, are as follows:-

Mean Yields of Cocksfoot, Danish.

Grams of Dry Matter Per Cut.

Cutting Dates	Treatments.				
	N	S	M	V	X
10th Oct. '46	1.1	.8	1.5	1.5	1.9
21st Nov. '46	.8	.6	.9	.9	1.1
18th Dec. '46	1.2	1.2	1.1	.7	.9
6th Feb. '47	1.6	1.2	1.1	1.0	1.1
25th June '47	1.8	1.3	1.4	1.4	1.2
Treatment Totals	6.5	5.1	6.0	5.5	6.2

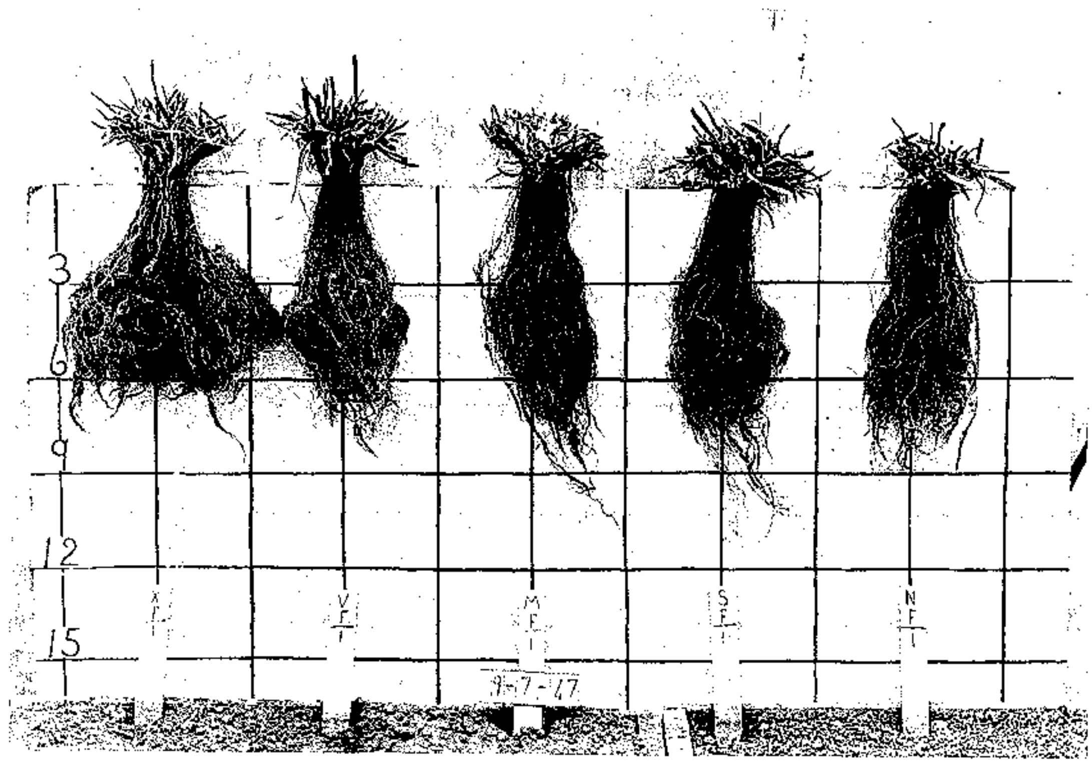
Yields were not as great as those of the Selected Cocksfoot and no yield differences are statistically significant.

The figures for the average percentage dry matter of the herbage in this series, are as follows:-

Treatment.	% D.M.
N	33.3
S	29.3
M	31.6
V	32.5
X	33.5

The roots of plants from this series display the same characteristics as those of the previous group, in having the large number of fine roots in the more acid treatments.

Average roots of each treatment are shown in the following photograph.



The mean dry weight of roots in this series are as follows:-

Treatment	Average Root Weights Grams Dry Matter.
N	4.8
S	3.4
M	4.0
V	4.0
X	8.6

Series "G". Red Clover, Broad.

Owing to the death of the original clones in this series and the replacement with selected seedlings in September, the first measurement of herbage from these plants was delayed until February 1947. By then most of the plants were growing actively except for those of "X" treatment which at no time compared favourably with plants of the other treatments. Certain of the plants in "X" treatment appeared to be infected with virus, and plant X.1 was not healthy at the close of the experiment while X.2 actually was dead.

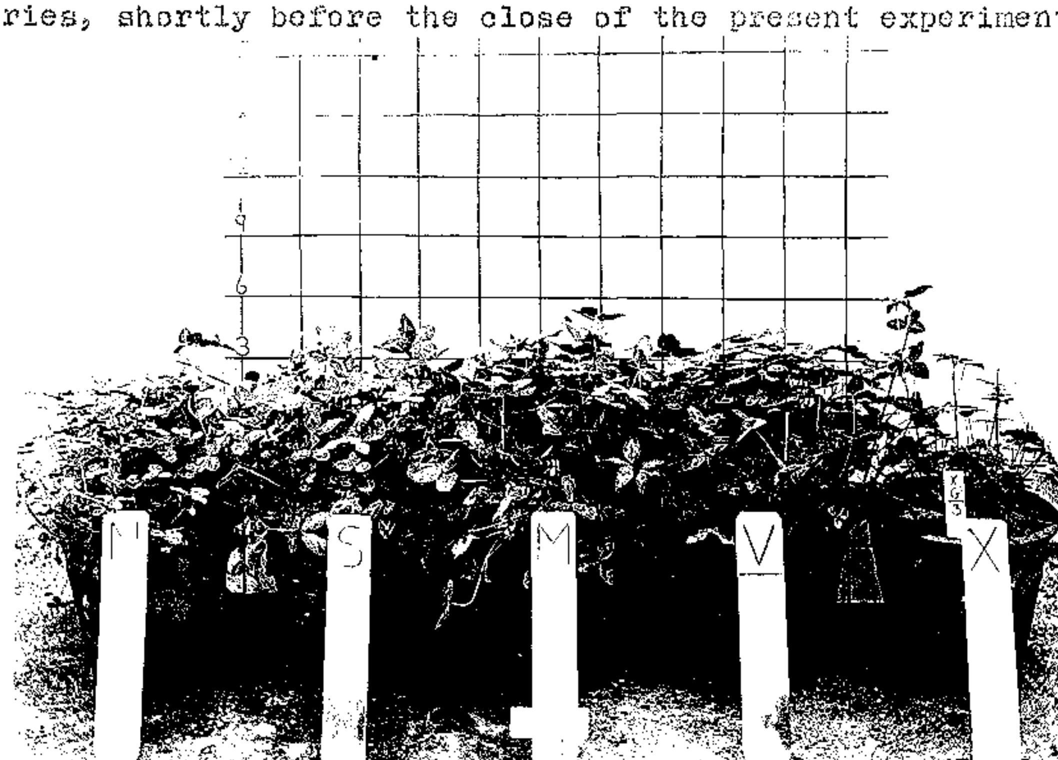
The mean yields of all replications in treatments at each cut, expressed on a dry weight basis, are as follows:-

Mean Yields of Red Clover, Broad.

Grams of Dry Matter Per Cut.

Cutting Dates.	Treatments.				
	N	S	M	V	X
3rd Feb. '47	28.8	26.4	30.8	23.6	16.6
5th March'47	4.8	4.6	6.0	5.6	2.9
29th May '47	10.8	11.4	13.7	15.3	4.0
Treatment Totals.	44.4	42.4	50.5	44.5	23.5

The following photograph shows typical plants of each treatment in this series, shortly before the close of the present experiment.



It can be seen that the "X" treatment plant is not thriving and the yield figures show that this treatment is significantly lower than all the others. When the other treatments are compared, it is found there is no statistical significance between their mean yields. Thus in the case of Broad red clover, the level of soil acidity has had no deleterious effect on yields until the pH was reduced below 4.7.

The mean figures for dry matter percentage are as follows:-

Treatment.	% D.M.
N	22.6
S	23.8
M	24.5
V	22.7
X	25.5

The characteristics of the roots in this series are shown in the following photograph:-

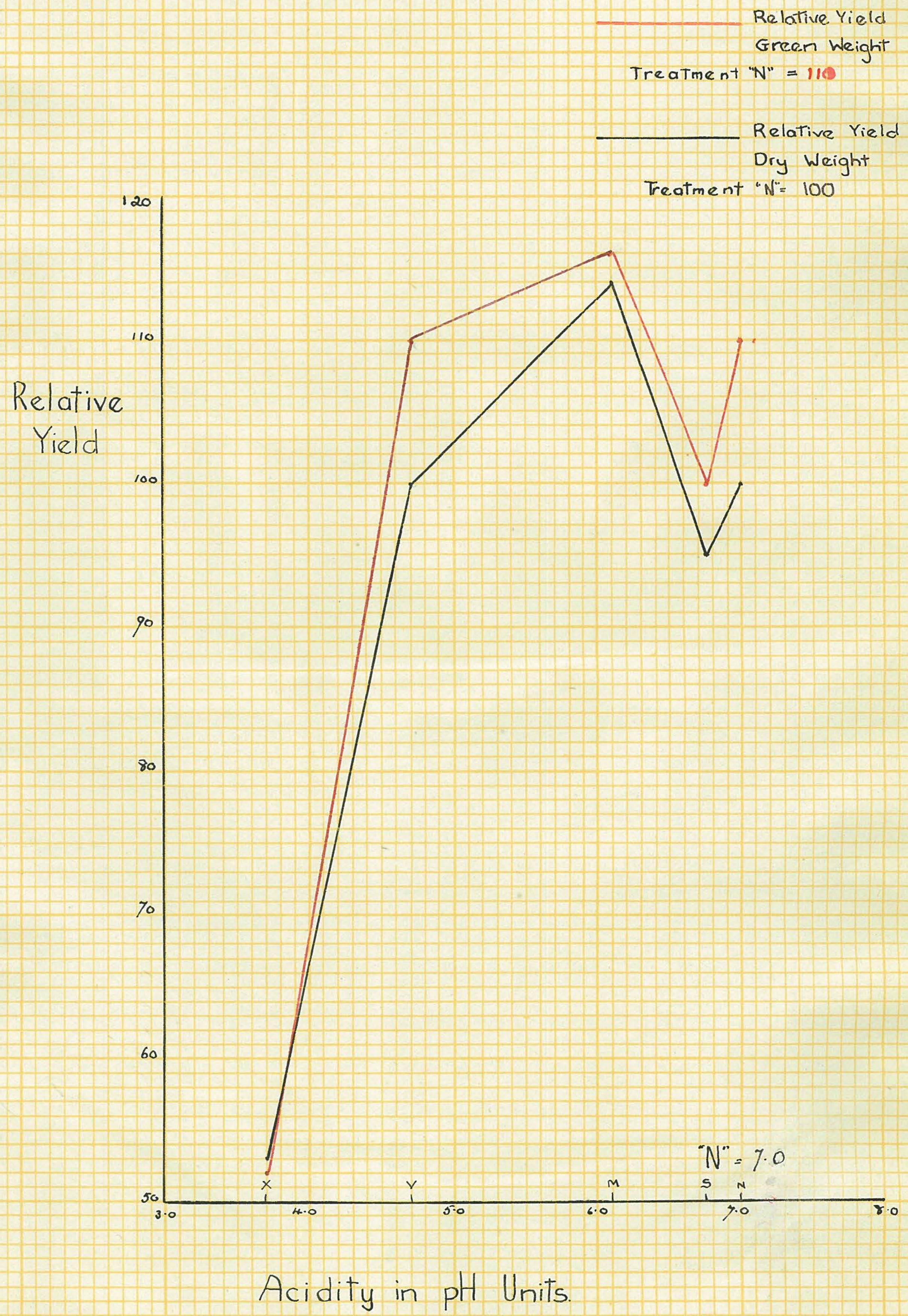
The average dry weights of the roots in this series are as follows:-

Treatment.	Average Root Weights Grams Dry Matter.
N	52.0
S	24.6
M	38.5
V	14.4
X	12.1

These figures are of special interest, because in the grasses the root weights as a whole tend to remain the same, or even to increase with decreased pH level, but in this red clover, except for treatment "M", the root weights decrease with decreasing pH.

The following graph compares relative yields of treatments in this series:-

Relative Yields of Broad Red Clover at Various Levels of Soil Acidity.
Series "G."



Series "H". Red Clover, Montgomery.

In this series, the plants were fairly slow in becoming really established and only a small proportion of herbage yield was produced during the first five months.

The mean yields of all replications in treatments at each cut, expressed on a dry weight basis, are as follows:-

Mean Yields of Red Clover, Montgomery.

Grams of Dry Matter Per Cut.

Cutting Dates.	Treatments.				
	N	S	M	V	X
7th Nov. '46	7.6	10.5	12.0	5.3	2.0
8th Jan. '47	49.0	73.0	70.0	55.0	13.0
5th March'47	14.2	20.8	23.8	16.6	11.6
29th May '47	13.7	17.5	17.1	11.9	2.9
Treatment totals	84.5	122.0	123.0	89.0	30.0

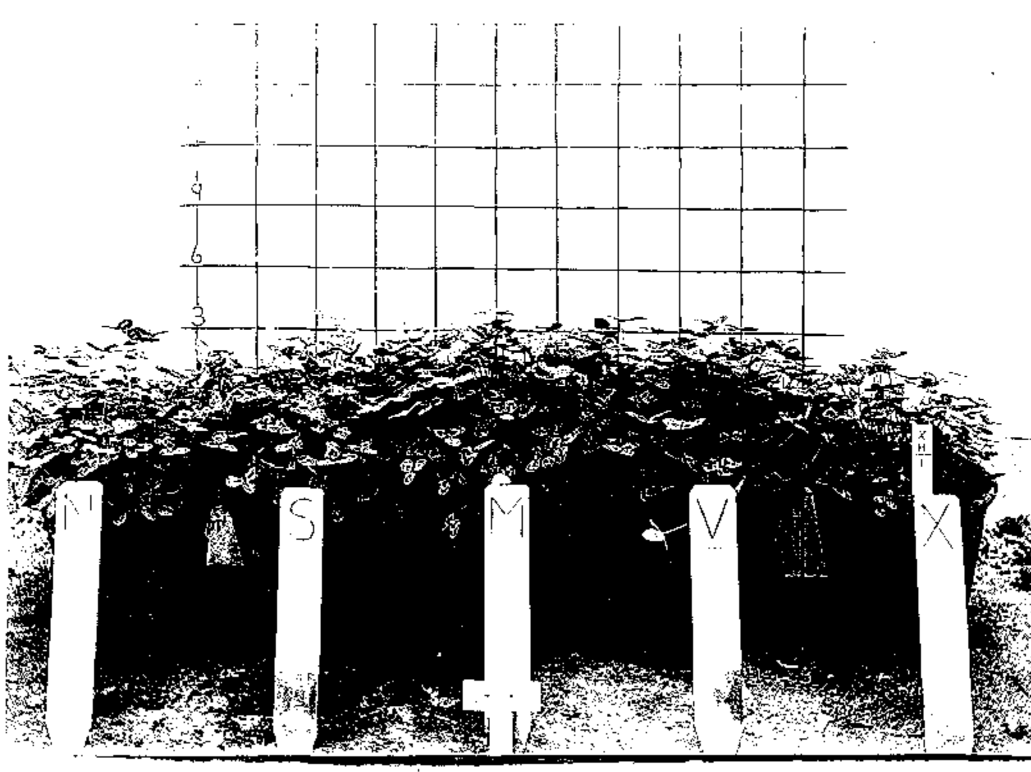
After the cut in November, growth was very rapid and over half the total year's growth was produced during the next two months. After this time, production was comparatively even, and in most treatments the growth from 8.1.47 to 5.3.47 was much the same as from the latter date to 29.5.47, when the last measurement was taken. As far as yields are concerned, that of treatment "X" is obviously the lowest so we can say the yield has been greatly decreased by an acidity level of pH 3.7. The analysis of yield data shows that the superiority of "S" and "M" treatments over other treatments is highly significant, while there can be no significance attached to the minor differences between yields of "N" and "V" treatments or between "S" and "M". Thus we can say that in the case of the Montgomery red clover, the greatest yields have been obtained at pH levels of 6.75 and 6.1, while those at 7.0 and 4.7 were equal to each other and greatly superior to yields at pH 3.7.

As far as percentage dry matters are concerned the mean figures are as follows:-

Treatment.	% D.M.
N	24.0
S	23.0
M	22.8
V	23.0
X	30.0

It will be noticed that these figures are comparatively even except that the "X" treatment herbage has a higher percentage dry matter than the others. This increase might be expected in that slower growing plants usually have a lower water content than faster growing ones of the same species.

The following photograph illustrates typical plants of each treatment.



As mentioned previously (Section VIII) the nodulation on the plants in this series were of interest in that in the "V" treatment the nodules were not only larger but also more plentiful than on plants in less acid treatments. In the "X" soils, the plants had fewer nodules, but those present were very large.

One of these can be seen in the following photograph, at the end of the pointer.

The weights of the roots in this series are as follows:-

Treatment.	Average Root Weights Grams Dry Matter.
N	52.4
S	44.8
M	26.8
V	15.6
X	10.5

It is seen here that there is no correlation between root weights and herbage yield, as the two treatments that gave the highest yields have only intermediate root weights. The root weights here decrease regularly with increasing soil acidity and appear to be correlated directly with this factor.

A comparison of the yields of the treatments in this series, is seen in the following graph:-

Relative Yields of Montgomery Red Clover at Various Levels of Soil Acidity.

Series "H"

Series "I". White Clover, Type I.

The plants of this series became established more quickly than those of the former series, and were first cut four months after planting.

The mean yields of all replications in treatments at each cut, expressed on a dry weight basis, are as follows:-

Mean Yields of White Clover. Type I.

Grams of Dry Matter Per Cut.

Cutting Dates	Treatments.				
	N	S	M	V	X
17th Oct. '46	5.2	4.5	7.6	4.1	5.3
11th Nov. '46	4.2	5.7	11.0	10.7	3.9
7th Jan. '47	16.4	23.1	30.2	32.3	11.5
10th March'47	11.2	20.4	26.6	26.6	3.7
29th May '47	6.8	11.4	12.1	15.5	.4
Treatment Totals	43.8	65.1	87.5	89.2	24.8

It will be seen that, as with the Montgomery red clover, the period of greatest growth was between 11th November, 1946 and 7th January, 1947, when approximately one third of the total growth was recorded/ After this period however, growth was still good, and the weight recorded for the two months to 10th March was nearly as great as that for the preceding two months.

As far as total yields are concerned, it is seen that the "V" and "M" treatments have each given the same production and that this has been significantly greater than any of the other three treatments. Treatment "N" has yielded only half as much as treatment "M" or "V", while the yield of "X" is half that of "N". Treatment "S" was intermediate in production when compared with "N" and "M" treatments. Thus the production of the treatments steps evenly, each step being approximately 20 grams in the mean yield, from pH 3.7 to 7.0, to 6.75 and finally reaches a wide peak at pH 6.1 and 4.7.

The following photograph taken on 13th November, 1946, of a characteristic plant from each treatment in this series, gives a good indication of the relative production of the plants in this series.

Photo.. 13th Nov. 1946.

The following photograph shows the condition of the plants in this series towards the close of the experiment.

The percentage of dry matter in the herbage of this series was as follows:-

Treatment.	% D.M.
N	24.6
S	24.3
M	22.1
V	22.6
X	27.6

These figures appear to be correlated inversely with the total herbage yield, as one might expect.

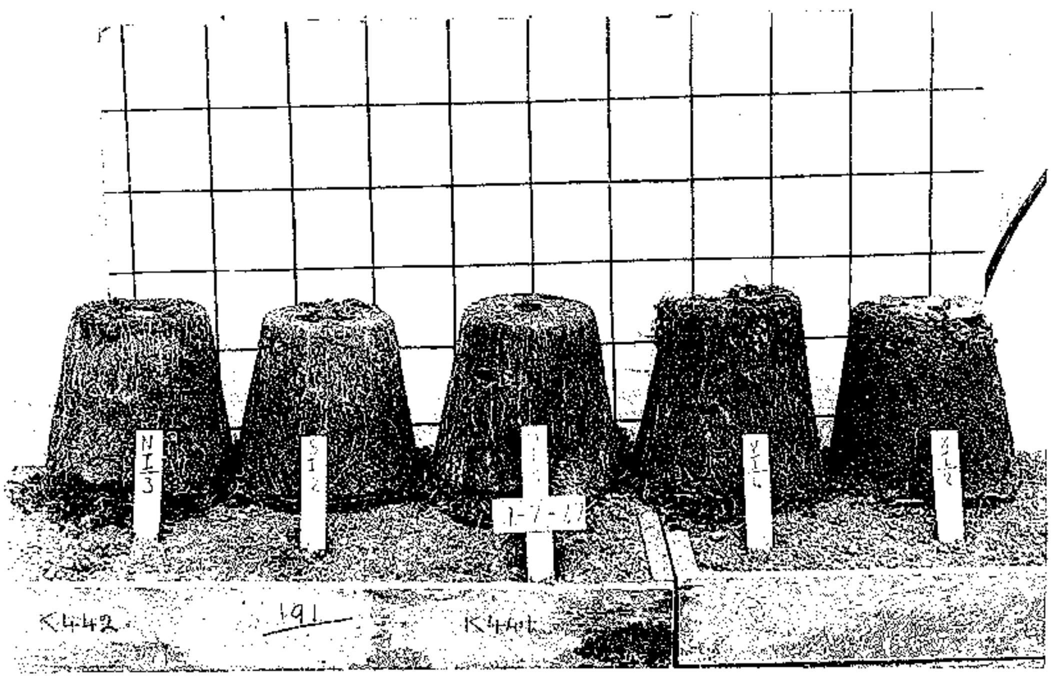
Counts were made of the number of flower heads on the plants in the different treatments, but acidity appeared to produce no effect as far as these were concerned.

The following is a summary of the total flower heads produced by an average plant in each treatment in this series:-

Treatment.	Total Flowers Per Plant.
N	94
S	95
M	92
V	79
X	92

An attempt was made to separate the roots from the soil, but this was not possible with either white clover owing to the fact that the roots broke very readily during handling, so no root weights have been obtained for series "I" or "K".

The following photograph shows the soil and plant roots turned out of the pots at the close of the experiment and demonstrates the degree to which the root systems vary in the different treatments.



The most obvious effect of the high acidity is that the soil in the "X" treatment is breaking away, as the roots are not bound around the soil as in the other treatments. It has been noticeable right through the experiment with all the clover series, that the root systems have been much restricted in the extremely acid soils.

The following graph compares mean yields of this series:-

Relative Yields of White Clover at Various Levels of Soil Acidity.

Type I.

Series "I."

Series "K". White Clover, Type II.

The plants of this series established more slowly than did those of white clover, type I, but once the plants were growing well, production continued until the close of the experiment. In this case too, most of the production took place in the summer months, and over two thirds of the total herbage for the twelve months was produced from 21st November, 1946, to 6th February, 1947.

The mean yields of all replications in treatments at each cut, expressed on a dry weight basis, are as follows:-

Mean Yields of White Clover, Type II.

Grams of Dry Matter Per Cut.

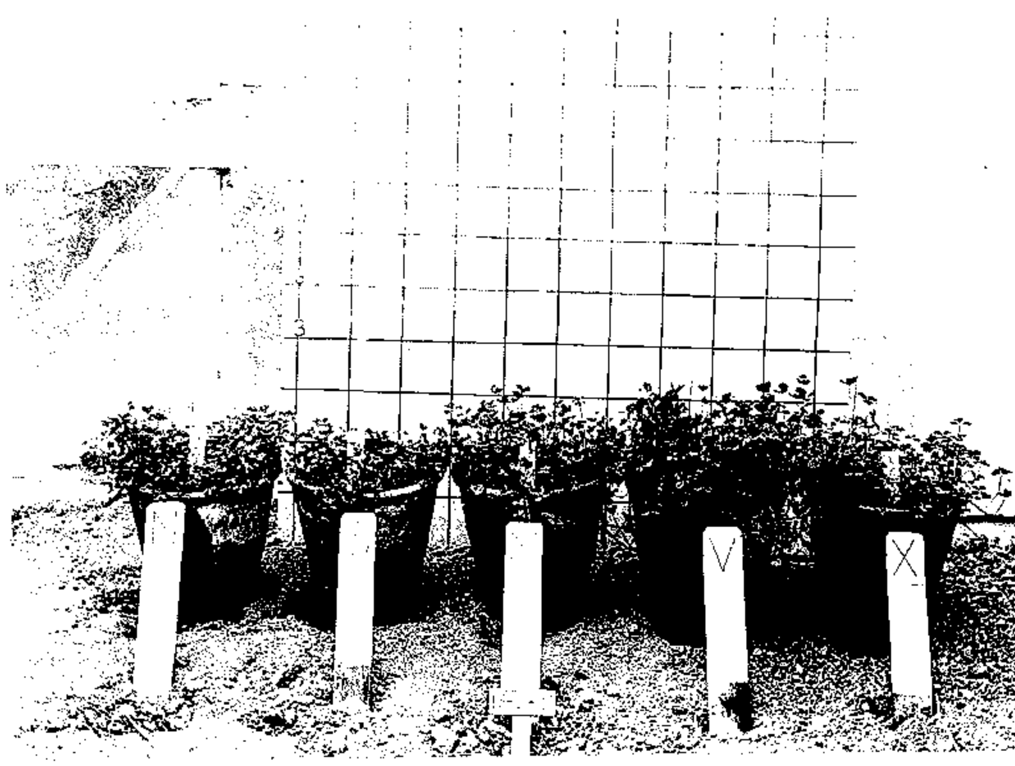
Cutting Dates.	Treatments.				
	N	S	M	V	X
21st Nov. '46	5.6	6.1	5.3	6.8	2.7
19th Dec. '46	11.3	14.2	13.0	19.2	8.5
6th Feb. '47	7.1	9.3	10.6	16.0	8.7
29th May '47	2.5	2.2	2.5	6.6	1.2
Treatment Totals	26.5	31.8	31.4	48.6	21.1

In this series there is considerable variation within many of the treatments, but on analysis some difference between means are seen to be highly significant. Thus the production of "V" treatment is seen to be much superior to that of any other, and the differences between "V", and "X" or "N" treatments are found to be highly significant, while those between "V" and "S" or "M" are significant. Owing to the variation within the treatments the differences between "N", "S", "M" and "X" are nonsignificant.

We can say therefore that this strain of white clover under present conditions produced most herbage when the pH of the medium was 4.7, and that there was no significant difference between yields at other pH levels between 3.7 and 7.0.

Another point of special interest appears when mean yields of "I" series are compared with those of "K" series. Under treatments "N", "S", "M" and "V" the type I clover has produced approximately twice as much as the type II strain, but when the "X" treatment is considered it is found the productions are very similar in each strain. Thus it appears that the type II white clover may be comparatively more tolerant of extreme acidity than the type I strain.

The following photograph illustrates typical plants from each treatment in this series, as they were towards the close of this experiment.



When the figures for the percentage dry matter of the herbage are considered, the following average results are obtained:-

Treatment.	% D.M.
N	22.6
S	24.5
M	23.1
V	21.9
X	24.8

These appear much as one would expect, when the yield figures are considered, except that one might have thought the figure for "N" treatment would be somewhat higher and more in accord with that of "X".

Counts were made of the number of flower heads on the plants in this series at various times and the following totals means result:

Treatment.	Mean Total Flower Heads Per Plant.
N	85
S	94
M	99
V	101
X	103

An analysis of these figures shows that some of them are significant, a difference of 13.6 between means being significant at the 5% level. Thus the "M", "V" and "X" means are significantly higher than the "N" treatment, but there is no significance attached to differences between "S", "M", "V" or "X" treatments.

The graph on the next page compares yields of treatments in this series, while the one following that brings together relative yields in each of the series where significant differences exist between any means.

Relative Yields of White Clover
at Various Levels of Soil Acidity.
Type 2.
Series "K."

Comparative Herbage Yields.
[Expressed as Dry Weight.]

XII SECONDARY EXPERIMENT.

Germination and Establishment of Certain Pasture Species Under Acid Conditions.

After observing the way in which many of the pasture plants appeared to thrive better in a soil that was fairly acid as opposed to that nearly neutral, it was wondered whether the soils at different levels of acidity would exert any influence on the germination or establishment of seeds of several of the pasture species being used.

In order to test this, a seed box 2 ft. x 1 ft. x 3 ins. was prepared by dividing it crosswise into five separate compartments and one of each of these was filled with some of the spare soil from each treatment that had been taken from the soil heaps after mixing (Section V, Par. I.) and had been kept for just such a purpose. The acidities of the soils used in this experiment as measured a short time previously, were as follows:-

Soil Treatment.	pH.
N	7.2
S	6.75
M	5.95
V	4.5
X	3.6

Each compartment was then subdivided into five just by marking the soil and the box was then ready to be sown. It was decided to try the effect of these soils on the following seeds, Perennial ryegrass, Italian ryegrass, Montgomery red clover, Broad red clover and White clover and the following are the details of purity and germination of the lines of these used, as supplied by the Official Seed Testing Station of the Department of Agriculture, Palmerston North.

Plant Species.	Station No.	Percentage Purity.	Percentage Germination.
Perennial ryegrass	Ba 6719	99.8	99
Italian ryegrass	Bb 360	97.0	91
Mont. Red clover	Aa 611	98.0	78 plus 4
Broad Red clover	Aa 610	97.0	85 " 4
White clover	Ac 2565	99.8	94 " 2

NOTE:- In the germinations of the clover above, the number added to the main figure represents the percentage of hard seeds in the sample.

From the above lines of seed, one hundred seeds of each were picked out and carefully spaced between the subdivisions in each compartment so that there were in each compartment one hundred seeds of each line under test. These were then covered with a light dusting of soil corresponding to each treatment, and the whole box stood in a tray of water to provide moisture for germination without disturbing the seed placements. The following is the plan of sowing:-

<table>
<tr><th>N</th><th>S</th><th>M</th><th>V</th><th>X</th></tr>
<tr><td colspan="5">Montgomery red clover</td></tr>
<tr><td colspan="5">Perennial ryegrass</td></tr>
<tr><td colspan="5">Broad red clover</td></tr>
<tr><td colspan="5">Italian ryegrass</td></tr>
<tr><td colspan="5">White clover</td></tr>
</table>

This sowing was carried out on 25th October, 1946.

In order to demonstrate fully the rate of emergence and establishment of the seedlings, it was decided that the best method would be to take a series of photographs and to let these tell their own story.

The first photograph was taken one week after sowing:-

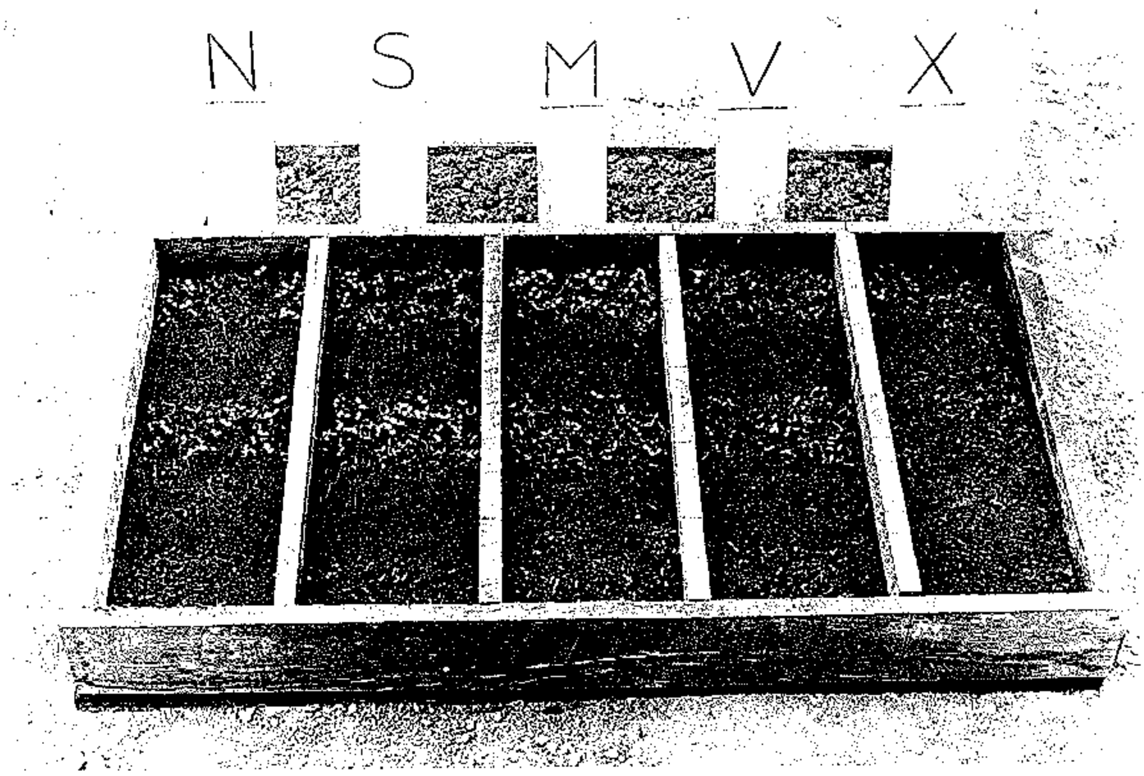


Photo taken 1st Nov. 1946.

It will be seen in the above photograph that the seeds of Montgomery red clover at the top of the picture are most advanced in the mediumly acid soil, as a larger proportion of these have their seed leaves opened out fully. The Broad red clover is most advanced in the slightly acid soil, while in the extremely acid soil very few plants are showing any of the lines of seed used.

The second photograph shows the picture two weeks from the sowing date:-

Photo taken 8th Nov. 1946.

Here again the "M" treatment is superior for the Montgomery red clover and also for the White clover at the bottom of the photograph. There is still almost no germination in the extremely acid soil, and even the very acid soil does not appear as good as the others.

This third photograph shows the growth just on four weeks after sowing:-

Photo taken 21st Nov. 1946.

At this time the extremely acid treatment is still having a bad effect on plant establishment, but the grasses that are established appear to be growing fairly well. The slightly acid soil appears to be retarding the growth of all the species growing there, when compared with the treatments on either side of it, while the medium and very acid ones are doing very well.

The last photograph taken five and a half weeks after sowing shows the growth two weeks before the experiment was finalized.

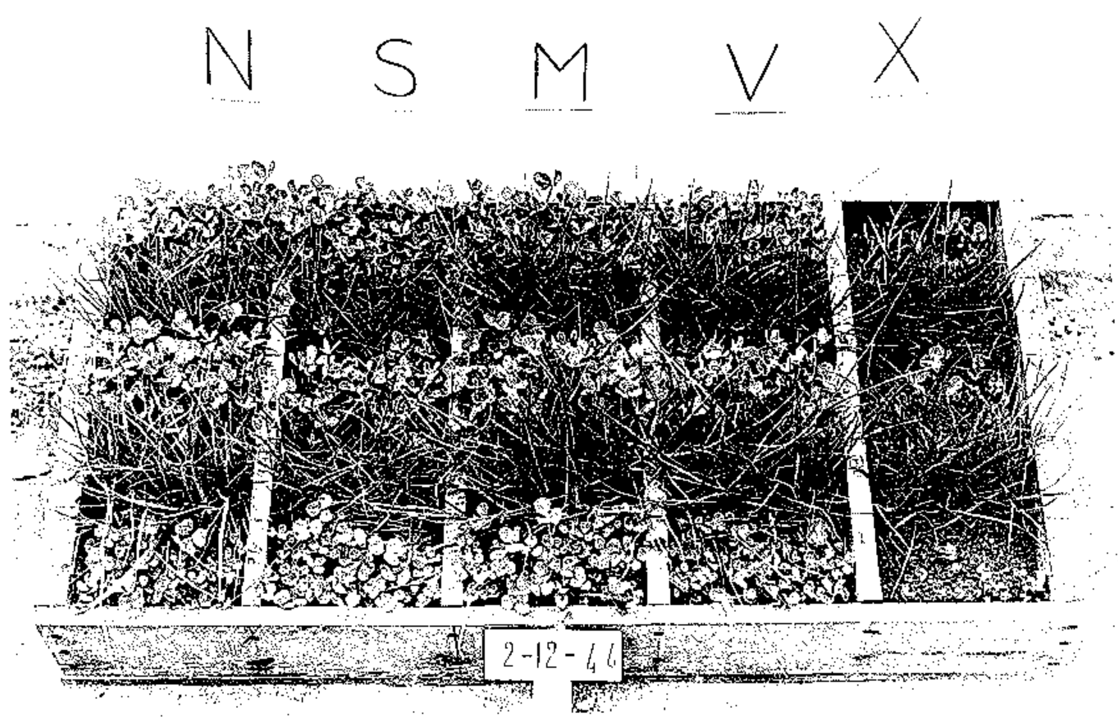


Photo taken 2nd Dec. 1946.

It can be seen that the "X" treatment is still the most rotarded, while the "S" treatment is not as vigorous as the remainder. The white clover appears best in the "M" series, while "N" treatment seems as good as any for most of the other species sown. On 16th December, 1946, each segment of soil containing one species in one treatment were cut out of the box and removed for convenience in handling. All the plants in that section were then cut off at ground level, counted and weighed.

The following are the data resulting:-

Establishment Percentage.

	N	S	M	V	X
Mont red clover	63	66	75	76	18
Broad red clover	68	44	65	71	14
White clover	53	63	65	68	8
Perennial ryegrass	90	86	84	100	79
Italian ryegrass	85	68	72	87	58

Actual Weight of all Plants Established, in Grams:-

	N	S	M	V	X
Mont. red clover	11	12	10	9	2
Broad red clover	10	6	10	7	1
White clover	6	11	11	10	1
Perennial ryegrass	6	5	8	9	6
Italian ryegrass	7	5	8	9	5

Dealing with each species in turn, the following results are obtained:-

	N	S	M	V	X
Mont. red clover.					
No. of plants from 100 seeds sown.	63	66	75	76	18
Relative N = 50	50	53	60	60	14
Total weight of these plants.	11 grams	12 grams	10 grams	9 grams	2 grams
Relative N = 50	50	55	46	41	9
Weight of 100 such plants.	17.5 "	18.2 "	13.3 "	11.8 "	11.1 "
Relative N = 50	50	52	38	34	32

Broad red clover.	N	S	M	V	X
No of plants from 100 seeds sown.	68	44	65	71	14
Relative N = 50	50	32	48	52	10
Total weight of these plants.	10 grams	6 grams	10 grams	7 grams	1 gra
Relative N = 50	50	30	50	35	5
Weight of 100 such plants.	14.7	13.6	15.3	9.9	7.1
Relative N = 50	50	46	52	34	24

White clover.	N	S	M	V	X
No. of plants from 100 seeds sown.	53	63	65	68	8
Relative N = 50	50	59	61	64	8
Total weight of these plants.	6 grams	11 grams	11 grams	10 grams	1 gra
Relative N = 50	50	92	92	83	8
Weight of 100 such plants.	11.3	17.5	16.9	14.7	12.5
Relative N = 50	50	77	75	65	53

Perennial ryegrass.	N	S	M	V	X
No. of plants from 100 seeds sown.	90	86	84	100	79
Relative N = 50	50	48	47	56	44
Total weight of these plants.	6 grams	5 grams	8 grams	9 grams	6 gram
Relative N = 50	50	42	67	75	50
Weight of 100 such plants.	6.7	5.8	9.5	9.0	7.6
Relative N = 50	50	43	71	67	57

Italian ryegrass.	N	S	M	V	X
No. of plants from 100 seeds sown.	85	68	72	87	58
Relative N = 50	50	40	42	51	34
Total weight of these plants.	7 grams	5 grams	8 grams	9 grams	5 gra
Relative N = 50	50	36	57	64	36
Weight of 100 such plants.	8.2	7.4	11.1	10.3	8.6
Relative N = 50	50	45	68	63	52

From the above results the following details can be obtained:-

	N	S	M	V	X
Total No. clovers from 300 seeds.	184	173	205	215	40
% clover establishment	61	58	68	72	13
Relative N = 50	50	48	56	59	11
Total weight of clovers from 300 seeds.	27 grams	29 grams	31 grams	26 grams	4 grm
Relative N = 50	50	54	57	48	7
Total weight per 100 mixed clovers.	14.7 "	16.7 "	15.1 "	12.1 "	10.0
Realtive N = 50	50	57	51	41	34

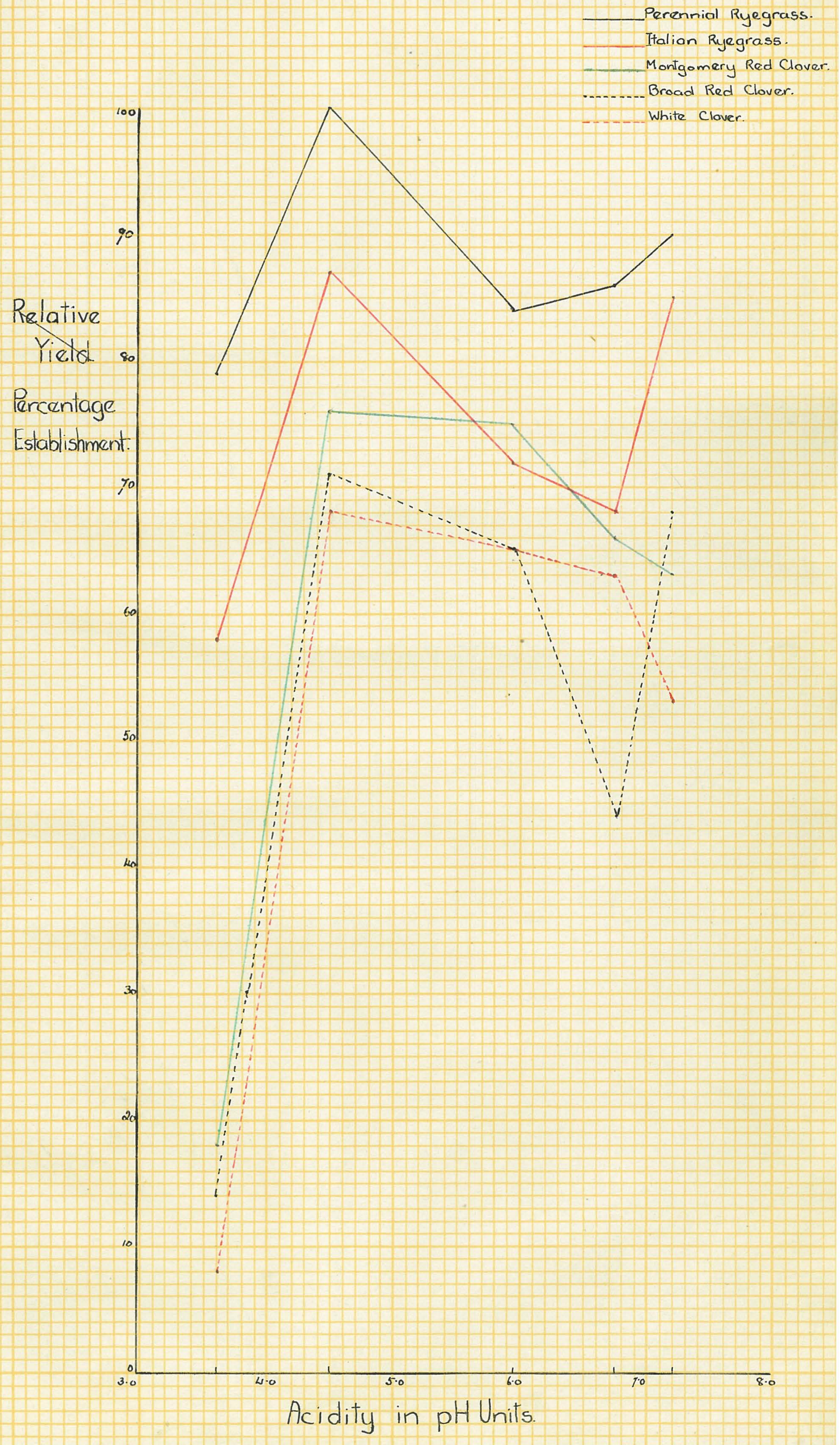
Total No. grasses from 200 seeds.	175	154	156	187	137
% grass establishment	88	77	78	93	69
Relative N = 50	50	44	44	53	39
Total weight of grasses from 200 seeds.	13 grams	10 grams	16 grams	18 grams	11 gr
Relative N = 50	50	38	62	69	42
Total weight per 100 mixed grasses.	8.6 "	6.5 "	10 "	10 "	8 "
Relative N = 50	50	38	58	58	47

	N	S	M	V	X
Total No. grasses and clovers from 500 seeds	359	346	371	402	177
% combined establishment	72	69	74	80	36
Relative N = 50	50	48	51	56	25
Total weight of plants from 500 seeds.	40 grams	39 grams	47 grams	44 grams	15 gms
Relative N = 50	50	49	58	55	19
Total weight of 100 mixed plants.	11.1 "	11.3 "	12.7 "	10.9 "	8.5
Relative N = 50	50	51	57	49	38

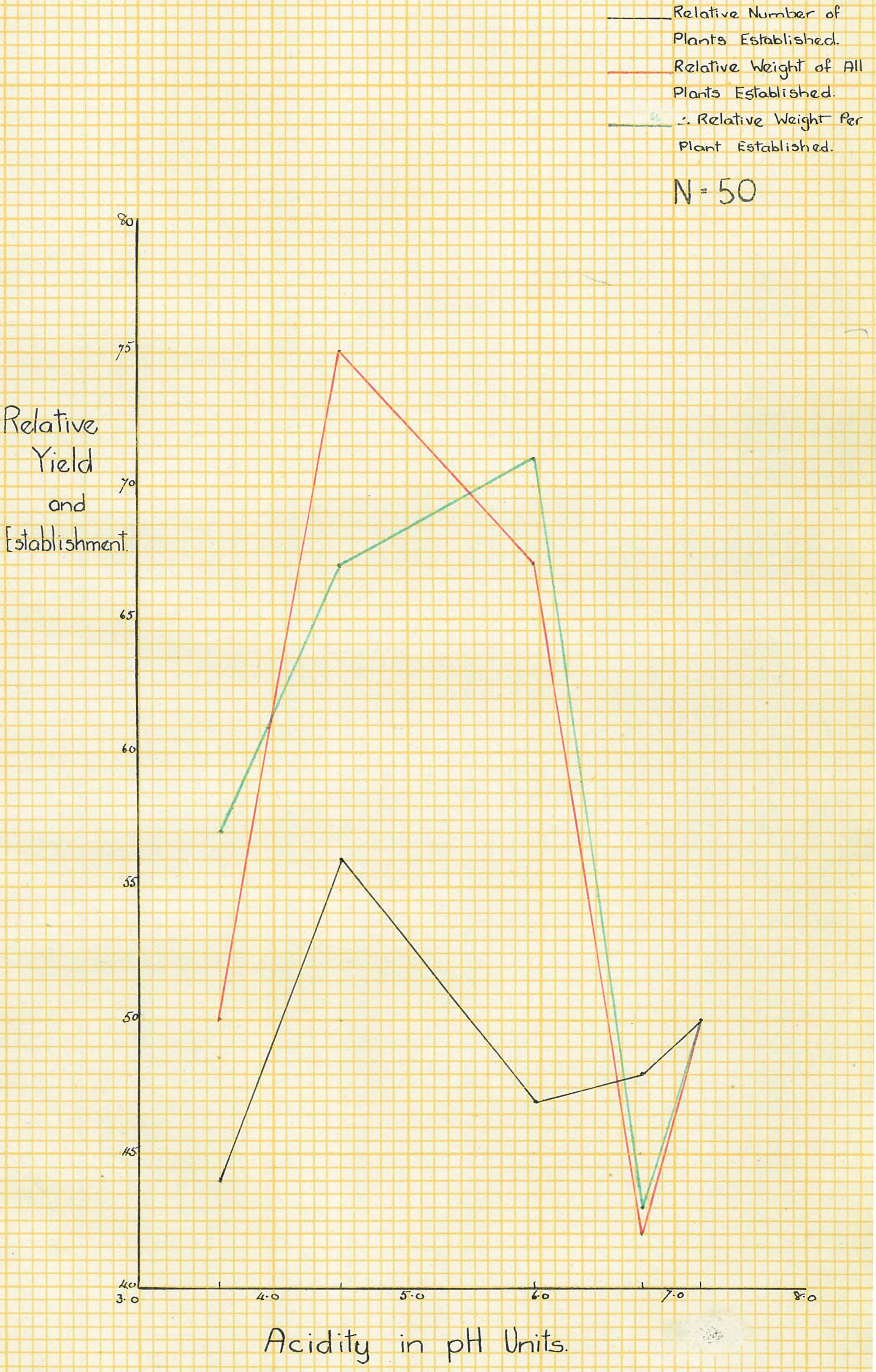
These results are illustrated by the graphs on the following pages:-

Percentage Establishment of all Species at Various Levels of Soil Acidity.

[Count Made 7½ Weeks After Sowing]

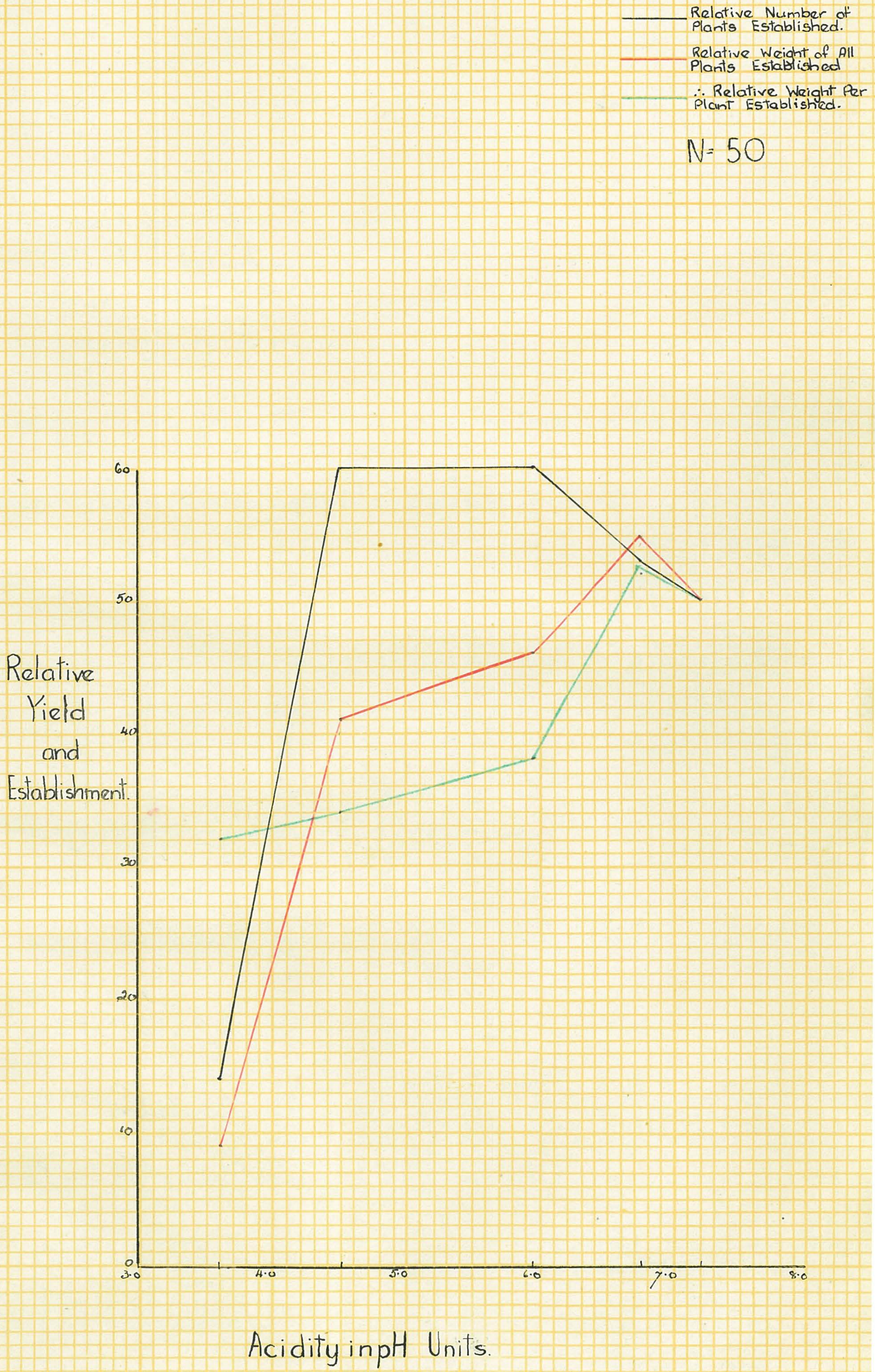


Perrenial Ryegrass:
Relative Establishment and Plant Weights
at Various Levels of Soil Acidity.
[Count Made 7½ Weeks After Sowing.]



Italian Ryegrass: Relative Establishment and Plant Weights at Various Levels of Soil Acidity. [Count Made 7½ Weeks After Sowing]

Montgomery Red Clover:
Relative Establishment and Plant Weights at Various Levels of Soil Acidity.
[Count Made 7½ Weeks After Sowing.]



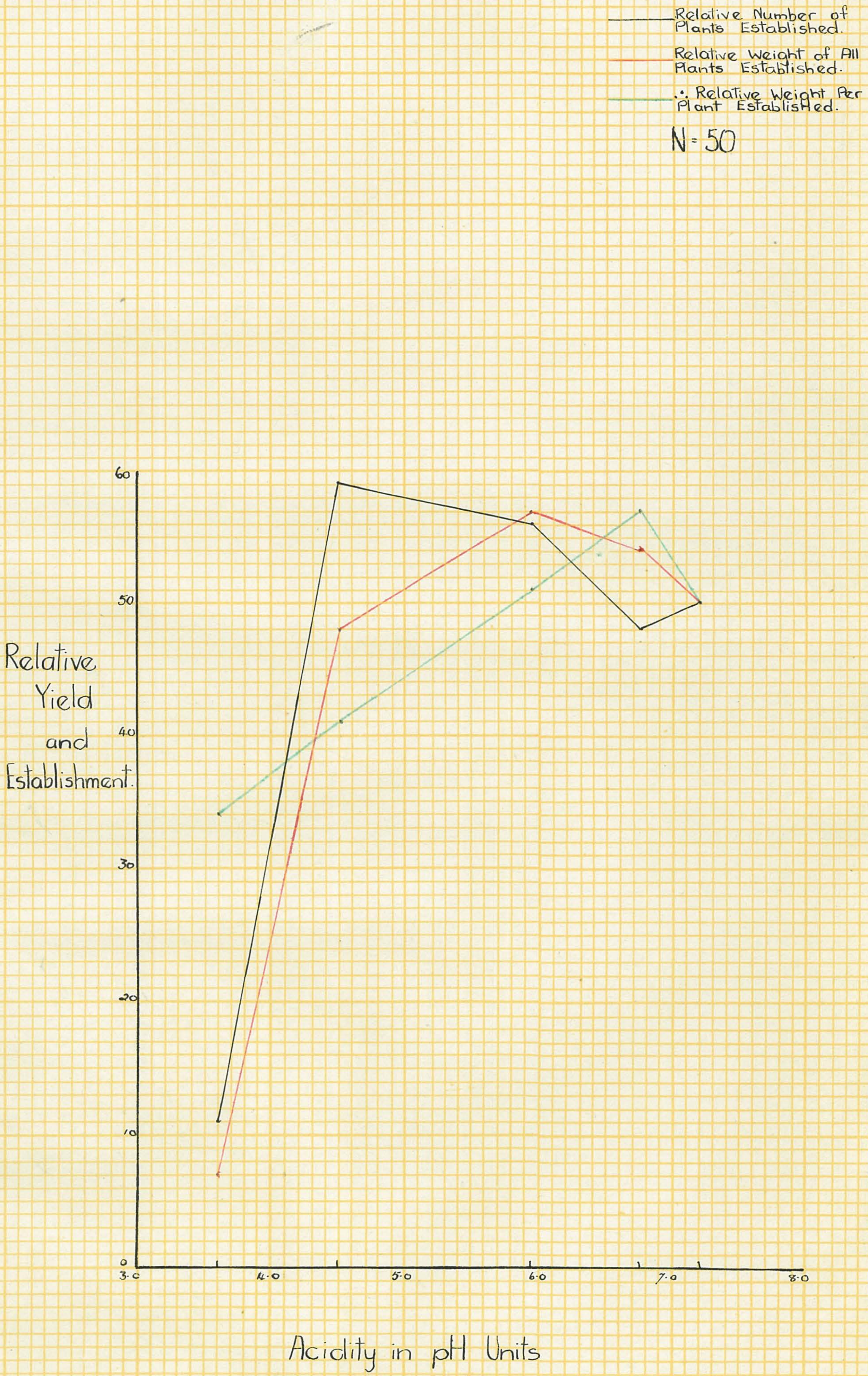
Broad Red Clover:
Relative Establishment and Plant Weights at Various Levels of Soil Acidity.
[Count Made 7½ Weeks After Sowing.]

White Clover:

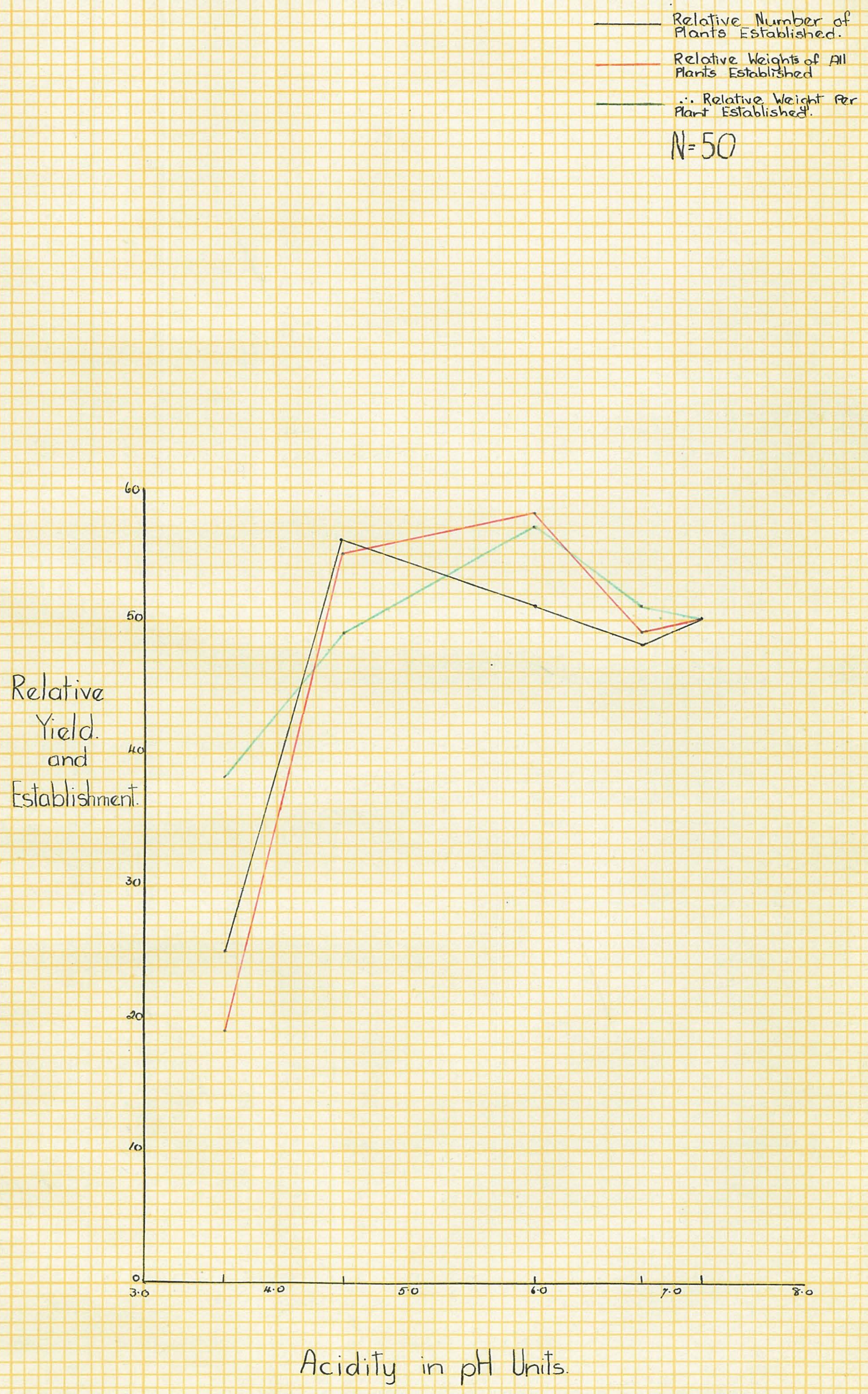
Relative Establishment and Plant Weights at Various Levels of Soil Acidity. [Count Made 7½ Weeks After Sowing.]

Combined Grasses:
Relative Establishment and Plant Weights at Various Levels of Soil Acidity.
[Count Made 7½ Weeks After Sowing]

Combined Clovers:
Relative Establishment and Plant Weights at Various Levels of Soil Acidity.
[Count Made 7½ Weeks After Sowing]



Combined Grasses and Clovers: Relative Establishment and Plant Weights at Various Levels of Soil Acidity. [Count Made 7½ Weeks After Sowing.]



After the completion of the trial of germination and establishment of various types of seed, another test was undertaken to see what effect acidity without the soil would have on the same lines of seed. To obtain well buffered solutions, as similar as possible, but having different pHs, solutions were prepared by Dr. Melville of Plant Chemistry Laboratory in which the buffering and pH were obtained by solutions of two salts in different proportions. These were .05 Molar solution of citric acid and disodium phosphate, and the proportions were adjusted to produce pH levels similar to those used in the germination experiment. These were as follows:-

Treatment.	pH level.
N	7.2
S	6.8
M	6.0
V	4.5
X	3.6

The lines of seed used were the same as those in the soil experiment

Montgomery red clover	Aa 611
Broad red clover	Aa 610
White clover	Ac 2565
Perennial ryegrass	Ga 6719
Italian ryegrass	Gb 360

One hundred seeds of each line were placed on filter paper in a large petre dish and each petre dish was watered with its own special solution. As a check of the results, one hundred seeds of each line were also placed on, and covered with filter paper for the germination test as regularly carried out at this station.

The table showing the percentage germinations at the end of 10 days, appears on the following page:-

	Water Control	N	S	M	V	X
Aa 611	94	79	50	68	88	89
Aa 610	92	86	35	69	87	83
Ac 2565	91	74	18	42	63	57
Ba 6719	98	98	96	100	98	98
Bb 360	88	88	81	92	94	90

From these figures the most striking result is the fact that the water control gave the best all round germinations, and in fact gave the highest germinations in all cases except that of Ba 6719 and Bb 360. Even then it is possible that no significance can be attached to the increase of Ba 6719 from 98% to 100% in the "M" treatment, but in the case of Bb 360 the tendency appears to be for germination to be better in the more acid treatments, than in the water control.

One very noticeable fact in the above, too, is that the "S" treatment consistantly gives the lowest germinations recorded. Also something very striking is that the germination in the "X" treatment with the acid solution are very much higher than the percentage establishment in soil at the same pH.

Apart from these points, the figures are fairly well in accord with those of the establishment in the acid soils, and in most cases they do not vary between treatment as much as one might expect.

The graphic presentation of the above results appears on the following page:-

Laboratory Germination Test:
Percentage Germination at Various Levels of Solution Acidity.
[Count Made After 18 Days]

XIII. DISCUSSION OF RESULTS.

Soil Acidity.

As far as methods of making soils acid are concerned any of the methods reported seem fairly satisfactory, though probably fertilisers like sulphate of ammonia are not ideal, as many effects on plant growth may be due to toxic factors or a resultant poor soil condition, rather than the produced acidity. Apart from this it would appear that flowers of sulphur produce very good results, but if a quicker change is required and a method is desired where good control over the resultant soil pH is possible then sulphuric acid is a satisfactory material for the purpose in cases where the amount of soil to be acidified is not too large. Hydrochloric acid does not seem as suitable as sulphuric, while phosphoric acid, although satisfactory, gives acid treated soils an unfair advantage through the large amount of available phosphate present.

The changes in the pH levels of most of the treatments during the last six months of this experiment are very striking and the way in which the changes in the grass soil differed from that in the clover soil is most interesting. No literature has been found that helps explain these observations, except, as mentioned previously (Section II), that many plants appear to have the power of selective absorption or excretion of anion or cations, or some other method, so that they move the pH of their growing medium towards their optimum. Certainly plants in culture solutions aften alter the pH level to a marked degree (Arnon & Johnson, 1942, etc.) but no definite figures have been found to show similar changes in soils. A check has been made of numerous areas at Grasslands Division Station, and in every case the pH of top six inches of soil covered with red or white clover has been from 0.1 to 0.5 pH units lower than similar soil a few feet away with no clover in the sward. This of course may be explained by the extra calcium uptake by clovers when compared with grasses, but this does not seem sufficient to explain the results observed in this present experiment.

From an examination of the plant yields, the alterations in pH over the last six months appears to have caused no major changes in the plant reaction. Thus even though the pH of the "X" treatment has changed to almost the original level of the "V" treatment, the "X" yields have not increased and become equal to those of "V". A similar situation is seen with all the treatments and there appears to be no significant change in the order of yields among treatments despite the alteration in pH. Thus to allow simplication for purposes of graphs of yields and conclusions drawn, the pH levels of the different treatments have been taken as that of the soils as they were mid-way through the experiment - i.e. after six months. These are repeated here for convenience:-

	Reaction as pH Units - after six months.	
Treatment.	Grass Soils.	Clover Soils.
N	7.2	7.0
S	6.8	6.75
M	6.0	6.1
V	4.9	4.7
X	4.0	3.7

Plant Response.

The most obvious response of the plants in this experiment was the way in which clover growth as a whole differed from that of the grass growth. The grasses grew fairly actively in the early part of the experiment and some were cut for measurement at least a month before the first of the clovers. However in the second half of the trial grass growth was very poor indeed, the plants only just existing, and not thriving or producing growth comparable with that of similar plants in the field. The clovers were slower in starting active growth, but thrived well and each of the clovers greatly outyielded the best of the grasses. Even at the close of the experiment the clovers were still thriving and looking really healthy.

It appears possible that the difference between the grass and clover growth might be due to the fact that the clovers could obtain nitrogen supplies through the action of their symbiotic Rhizobia, while after the grasses had used the nitrogen stocks in the limited soil in the pots, they were nitrogen starved. If nitrogen was the limiting factor it could hinder growth so that soil reaction would not produce an expression in the plant growth at all. Certainly it might have been ideal to have tried adding nitrogen to some of the grass series to see what the response was, but as this was not done it is intended to make such a trial the basis of further study. It had been planned to add a series of nutrients to each treatment of all the grasses and clovers in an attempt to clarify the results observed, and if possible to decide whether the improved growth in certain treatments was due to a nutrient or a direct acidity response. Thus for the five replications in any series and any treatment the following applications were planned:-

Plot No.	Application.
1	Control
2	Phosphate only (Ca PO_4)
3	Nitrogen only NH_4NO_3
4	Complete nutrient, as for water cultures.
5	In "W" and "Y" treatments lower pH with sulphur. In "V" and "X" raise pH with Ca $(OH)_2$.

Such a use of the various replications would have spoilt their value statistically and for this reason such additions would not have been made early in the experiment. Thus it would appear that the wisest course was just to finalise the present experiment in the way planned at the commencement, and to make a trial such as that mentioned above, the basis for further experimentation at a later date.

The fact that the soil used in the pots was sterilised before using should not have been a cause of the poor grass growth resulting in this experiment, because this sterilization process should stimulate the activities of ammonifying organisms if not the nutrifying ones. Also the soil around the clones at the time of final planting contained a proportion of normal soil which should have provided an ample source of organisms for the invasion of the treated soils if others had been destroyed.

As far as the actual plant species are concerned, the first point of interest is the superiority of the series "B" (Type 3 Perennial ryegrass), over series "A" (Type I Perennial ryegrass) in treatments "M" and "V". This is difficult to account for, especially when yields of "N" and "X" treatments are lower in the "B" series, but it may indicate that the fairly acid conditions suited this particular ryegrass type and allowed the plant to develop better, especially in the earlier stages when most of the growth was recorded. With series "A" however, the yields are almost the same in all treatments, indicating perhaps that this type of plant, normally a much higher producer than the other, demands a more ideal environment for production, than that ruling in this experiment. Thus it is known that type I Perennial ryegrass thrives best with ample supplies of nitrogen, and this element was probably in low supply in the present experiment.

In the case of the Italian ryegrass (series "C"), the tendency of the treatment yields is similar to that of series "B", in that "N" and "X" treatments are lower in yield than are the other three, but the replications are so variable that no significance can be attached to any differences between means.

Short Rotation ryegrass presents a different picture from that of any other grass in this experiment, in that the yield of treatment "M" is lower than that of any other. No differences in mean yields in this series are significant, but there does appear to be a tendency for the particular conditions of the "M" treatment to be the least ideal for the growth of this particular plant.

Where the Cocksfoot series (Series "E" and "F") are concerned, the plants never became well established and production was always comparatively low. No differences between means can be significant, but it is noticeable that "N", "M" and "X" treatments are slightly higher than the other two in each series. Also in all treatments the Selected strain has slightly outyielded the Danish type.

When we come to the clover series, we at once notice the marked increase in yields, in all series, when these are compared with the grasses. Broad red clover is usually considered to be very much a lover of neutral or even alkaline conditions, so it is of considerable moment that in this experiment its yield has not been decreased significantly until a pH below 4.7 is reached.

Montgomery red clover, on the other hand has given its maximum yields in the "S" and "M" treatments, and there the average weights have been nearly 50% higher than those of treatments "N" and "V". So Montgomery strain differs from the Broad strain in that the former appears to thrive best at pH levels of 6.1 and 6.75 while the yield of the latter was not affected by the acidity between pH of 7.0 and 4.7. Both however are alike in that pH of 3.7 had a deleterious effect upon yields. Thus these results are much as expected, with the most acid soil retarding red clover growth, and the the case of the Mongomery strain maximum growth between pH 6.0 and 7.0.

The reactionsof the white clover strains are different from those of the other clovers, in that the peak production is found at a more acid reaction. In the type I (series "I"), the yield increases from treatment "N" to "S" then from "S" to "M". It stays at this level for "V" before falling sharply to "X" treatment. In the case of type II (series "K") however, the yield rises from "N" to "S", stays the same for treatment "M" before rising still further to a peak at "V" then falling sharply to treatment "X". Here it is of interest too, that while the yields of Series "I" are approximately double those of series "K" for treatments "N", "S", "M" and "V", yet in the "X" treatment the yields are nearly the same in each. This may indicate perhaps that the lower producing strain is able to produce a higher proportion of its maximum yield under extremely acid conditions, than is the normally higher producing strain.

It will be noticed that these results with white clover are contrary to the generally held opinion that this species thrives only under alkaline or near alkaline conditions. Certainly in practice on the average farm liming does appear to help induce clover growth, but any evidence that this is due to a reduction in acidity is inconclusive. As mentioned earlier (section II, Par. 2.), white clover is known to grow at low pH, and many writers include it with plants growing over a wide range of acidity. Owing to the fact that white clover herbage normally contains a high percentage of calcium, it is possible that liming is beneficial to clover growth because of the calcium supplied rather than because of the decrease in soil acidity. Some workers such as Albrecht have secured equal growth increases using gypsum that did not alter soil pH as using lime that did. Klapp (1938), found that in Germany, Trifolium repens was one of the most frequently occuring pasture species on all soils of pH varying from 3.4 to 8.5. Donald (1941), explains such results as being "due in part to the great degree of polymorphism in this species."

When great variation is observed between the reactions of different pasture strains to similar conditions, it makes one wonder just what the logical explanation can be. However it would seem that the most outstanding point demonstrated in this trial is the very wide range of soil reactions at which grasses and clovers will grow, and apparently grow normally and even thrive. Of course this is possible only when ample nutrients are available and if a certain level of acidity hinders the availability or absorbtion of some essential nutrient then plant growth must be reduced at that acidity. However, in this instance, Broad red clover produced equally at pHs between 7.0 and 4.7, Montgomery red yielded best at pH levels of 6.75 and 6.1, White clover, type I was most prolific at pHs of 6.1 and 4.7, while White clover, type II produced best at pH 4.7. Thus one might suppose that within this range at least the supply of available nutrient may be sufficient for plant requirements. Of course it is very possible that between species or even between strains, of the same species, there is a difference in the ability of the plants to utilize or absorb nutrients, or even a difference in the reaction to chemicals that may be toxic to some plants but not to others.

Thus it would seem possible that when it is observed that one plant out-yields another at a high level of soil acidity, this may not be due directly to the fact that one prefers a lower pH than the other, (though such evidently is true with certain plant species). It may instead be explained by the fact that one plant is better equipped than the other to obtain its required nutrients despite the high acidity, rather than because of it.

As far as the figures for percentage dry matters are concerned, it is remarkable how similar are the means, when all the series for each treatment are compared. Thus for treatments from "N" to "V" the mean percentage figures vary only between 27.0 and 27.4, and the only marked variation is for treatment "X" where the mean figure is 28.8. So although individual series fluctuate to a minor extent between treatments the averages when all the series are considered are very similar.

When the weights of the plant roots are considered, the main difference noticed is that between the grass root figures and those for the red clover. Among the grasses, apart from the abnormal yield of "N" in series "A" and yields of series "D", it is seen that the weights of roots in treatment "X" are fairly consistantly higher than the other treatments, while in the two clovers recorded the weights of the "X" treatment are even more consistantly lower than the others. Thus it would appear that extremely acid conditions may lead to an increase in the root systems of most grasses, possibly as an expression of their attempt to reach less acid soil or to obtain certain nutrients not available at the acidity, while a similar soil reaction markedly reduces clover root growth. In the clovers these reductions of root systems and herbage yields could be interdependent or else both resulting from the same cause, such as a high Hydrogen-ion concentration of the growth medium, but in the case of the grasses, the root weights and herbage yields do not appear to be correlated in any way.

In the secondary experiment in which seeds of several pasture species were sown in the same soil as used in the main trial, several interesting facts emerge. The first of these is readily seen from the graph showing the actual establishment of all the species used (page 131). This is the fact, that, with every species tested the highest percentage establishment has been found in the "V" treatment. Also it is seen that the establishment of all the clovers has been very poor in the "X" treatment, while that of the grasses has not been so much affected. Apart from the numbers of plants established in the different treatments, the weights of these plants are of interest. Both the ryegrasses show very similar curves of herbage weight, but then each of the clovers has a distinctively individual graph. None of the graphic representations of the weights of the established plants in this secondary trial are similar to that of the herbage yield of the species in the main experiment, but the reaction of young seedlings to acid conditions could be expected to differ from those of established plants. Thus it is readily observed that the extremely acid treatment has had a more deleterious effect on young seedlings than it did on any growing plants in pots of the same soil.

When it was observed that the percentage of establishment within one species varied with the different treatments, it was thought probable that the weights of individual plants would be in inverse proportion to the number established, owing to the competition effect. However this was not the case, and in fact the graph of the weight of individual plants (expressed for convenience as the weight of one hundred such plants) bears a remarkable similarity to that of the weights of the total number of plants established. Thus it would appear that the factors that have affected the germination and establishment of the different species, have also similarily affected the weight of the established plants.

XIV. [illegible].

At this stage it must be stressed, that any conclusions drawn in this experiment apply only to the particular and perhaps unnatural conditions ruling in this experiment, and must not be used to bring about any alteration of normally satisfactory agricultural practices, such as liming pastures to encourage clover growth. Present results are of certain interest however, and may stimulate further research into this problem of establishment and growth of pasture plants under varying conditions of acidity.

XIV. SUMMARY.

1. A soil has been mixed with river sand and then brought to various degrees of Hydrogen-ion concentration. This has been effected by adding varying strengths of sulphuric acid to soil placed in 8 inch flower pots.

2.. The following are the reactions of the soil produced as a result of the treatments, as at the time when planting took place.

Treatment Designation.	Soil Type.	pH at Start of Experiment.
N	Neutral	7.2
S	Slightly acid	6.75
M	Mediumly acid	5.95
V	Very acid	4.5
X	Extremely acid	3.6

3. An experiment has been carried out in which various important pasture species were grown in flower pots containing the above soil treatments. Measurements of herbage yields were recorded for a period of approximately twelve months after the planting date.

4. The following were the species of pasture plants used in this experiment:-

Perennial ryegrass	Lolium perenne
Italian ryegrass	Lolium multiflorum
Short Rotation ryegrass	L. perenne L. multiflorum
Cocksfoot	Dactylis glomerata
Red clover	Trifolium pratense
White clover	Trifolium repens.

In the case of four of the above species, two distinct strains or varieties were grown in this experiment. These were:-

Perennial ryegrass.

Good strain Type I

Poorer strain Type III.

Cocksfoot

Good strain, Nucleus selection.

Poorer strain, Danish type.

Red clover

Early variety, Broad red clover or "cowgrass"

Late variety, Montgomery red clover.

White clover

Good strain, Type I

Poorer strain, Type II.

6. In each plant series, one plant was selected and divided so that clones were available for all replications and all treatments in any series.

7. The ryegrasses grew fairly well in the early stages of the experiment, but growth soon slowed down and was soon not comparable with that of similar plants growing normally in the field.

8. In the ryegrass series, (A to D) the only one in which any treatments showed significant differences between their means was series "B", Perennial ryegrass Type III. Here treatment "Y" was significantly higher producing than treatments "N" and "X".

9. The yields of the two higher yielding treatments in series "B" were greater than the highest in series "A".

10, The Cocksfoot plants in all treatments of series "E" and "F" grew very poorly and did not thrive at any stage during the experiment.

11. All the clover plants used were fairly slow in becoming established and did not produce much herbage during the first few months after planting, but during the latter half of the experiment they thrived in most soil treatments.

12. The Broad red clover clones planted, died of virus disease and were replaced by selected seedlings of a uniform line.

13. Many of the clover plants grew very well in the acid soils, the white clover strains being very vigorous even in the "V" treatment, and growing comparatively well even in the extremely acid soil.

14. The Broad red clover series gave yields that showed no significant differences between means from pH 7.0 to 4.7, but the yield at pH 3.7 was significantly lower than all others.

15. Montgomery red clover gave its highest production at pH levels of 6.75 and 6.1.

16. White clover, type I, on the other hand gave highest yields at pH levels of 6.1 and 4.7.

17. The production of White clover, type II was highest at pH 4.7.

18. The results suggest that in White clover strains, Type II may be more tolerant of very acid conditions than Type I.

19. The flowering of White clover, Type I plants was not significantly influenced by soil acidity, but with Type II, the more acid treatments produced more flower heads than did the neutral soil.

20. When percentages of dry matter in green herbage were considered, the means of all series for different treatments were very similar, except that the extremely acid treatment produced herbage of slightly higher dry matter content than the others.

21. In the case of the grasses, with few exceptions it was found that the highest average root weights were obtained from the extremely acid soils. With the red clovers however, the root weight decreased markedly with increasing soil acidity.

22. In a simple trial of germination and establishment of certain pasture seeds in acid soils, at the end of 7½ weeks, highest establishments of all species were found in the soil at pH 4.5. Each different species or variety of seed used, reacted differently both as far as establishment and weight of established plants

were concerned.

23. As a rule it was found that the weight of individual established plants was not inversely correlated with numbers of established plants, but that the factors that affect seed germination and establishment, appear to similarly affect the weight of plants established.

24. The level of Hydrogen-ion concentration in the soils altered during the course of the experiment, the change being especially marked during the latter six months.

25. The pH levels of the "grass" soils changed differently from those of the "clover" soils.

26. Various chemical tests were conducted to help give a picture of the suitability of the soil in the different treatments to act as a growing medium.

27. As this experiment was carried out in flower pots, the conditions for growth were not as ideal as they usually are in the "field" and no nutrients were added to any soils to attempt to improve conditions.

28. At the present stage of this investigation into growth of pasture plants in acid soils the results of this trial should not cause any alteration in normal agricultural practices such as liming of pastures, as any conclusions drawn can apply only to the particular conditions ruling in the present experiment.

29. From this experiment it would appear that the pasture species and strains tested can exist and even thrive despite a very wide variation in soil acidity. Thus the degree of nutrient availability and the presence or absence of certain substances in toxic amounts appear of more importance in determining the growth of pasture plants than actual Hydrogen-ion concentration itself, unless extremes of acidity or alkalinity are reached.

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