A STUDY

of

THE INFLUENCE OF ANIMAL MANURE AND CLOVER ON THE STRUCTURAL AND CHEMICAL CHARACTERISTICS AND THE EARTHWORM ACTIVITY IN A MANAWATU SOIL.

by

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THE SOIL TYPE

THE REVIEW OF LITERATURE

(a) THE INFLUENCE ON THE STRUCTURAL CHARACTERISTICS.

The Plant Roots

Microbial Activity

The Type of Cover

Lime and Manure

(b) THE INFLUENCE ON THE CHEMICAL CHARACTERISTICS.

The Phosphorus in the Soil

The Potash in the Soil

The Ammonia and Nitrate Nitrogen in the Soil

The Organic Matter in the Soil

(c) THE INFLUENCE ON EARTHWORM ACTIVITY.

Species and Distribution

Earthworm Population

Seasonal Activity

Its Effect on Soil Productivity

(a) Chemically and Biologically

(b) Physically

pasture production by the N.Z. farmer, particularly in the North Island, a full appreciation of the value of the grazing animal and clover in relation to pasture yield and composition is of prime importance. While knowledge concerning these factors has been steadily increasing over the past decade, due largely to the work of the Grasslands Division, D.S.I.R., little information is available relating to their effects on the soil itself.

The object of the present investigation was to elucidate as many of the effects of manure and clover as was practicable using as experimental material certain plots which formed part of a pasture trial being conducted by the Grasslands Division. Accordingly the following aspects were selected for study:

(a) the effect on the structural characteristics of the soil.
(b) the effect on the level of available nutrients in the soil.
(c) the effect on earthworm activity in the soil.

Although it is realized that these effects are not mutually exclusive of one another the results of the investigation are considered separately under these headings for the sake of clarity of presentation.

THE EXPERIMENTAL AREA.

The area concerned consisted of a series of plots laid down in the autumn of 1946 by the "Grasslands" Division to investigate the influence of animal manure and clover on pasture composition and yield. The major treatment involved the comparison of "return" with "no return" of dung and urine on grass swards with and without clover; within these two major treatments, six minor treatments involving various combinations of superphosphate and lime were included.

The trial, as shown in the diagram and photograph, was in duplicate and the six minor treatments arranged in reverse order.

Owing to the fact that the experiment was a "mowing trial" the animal manure required for the treatments was obtained from specially-harnessed sheep grazing an adjacent identical experiment being conducted under natural grazing conditions. The manure collected therefrom was added to the plots concerned in the present study, after each mowing, in amounts proportional to the dry matter produced.

THE EXPERIMENTAL PERIOD.

The period over which the present investigation extended was from March 1948 to March 1949, the first sample being taken on March 12th 1948 and the last on March 12th 1949. There was however considerable variation in the length of the individual studies; thus, the earthworm investigation occupied approximately eight months, while the phosphorus study extended over twelve months, the period being largely dependent on the amount of time and labour involved.

Since reference is made in subsequent sections to pasture growth it is important to mention that the rainfall and temperature conditions occurring throughout the experimental period were most favourable for pasture production. Growth, although showing natural fluctuations, was continuous over the whole twelve months.

THE SOIL TYPE.

The soil type on which the pasture trial was laid is described by the Soil Bureau as the "Manawatu loam" derived from river alluvium and of high fertility.

Plan
of
Experimental Area

Soil structure as defined by Baver ( ) is the arrangement of the soil particles, both primary (sand, silt and clay fraction) and secondary (aggregates) into a certain structural pattern. Complete specification of such a condition, even as an instantaneous value, is essentially impossible, and the task becomes even more involved if the variations in structure with time are to be described. Its evaluation, therefore, is made in terms of one or more of such related properties as porosity, aggregate size-distribution and permeability. In the present investigation the measurement of structure based on soil aggregates was adopted.

Under natural conditions in most soils a high proportion of particles fail to function as individuals but are associated into secondary units called aggregates. ( ) Aggregate formation in the soil requires a cementation or binding together of floculated particles and can only occur if colloidal material is present. The physical behaviour of a soil is strongly affected by the number, size, arrangement and stability of these secondary particles.

Factors affecting aggregate formation can be listed as follows:

(1) The Plant Roots
(2) Microbial Activity
(3) The Type of Cover
(4) Lime and Manure
(5) The Type of Mineral
(6) Alternate Wetting and Drying
(7) Alternate Freezing and Thawing
(8) Cultivation
(9) Drainage and Irrigation

Of these only the first four are relevant to the subject and will be reviewed in detail.

1. The Plant Roots: Although all the workers agree that roots play an important part in stable aggregate formation their exact role has yet to be elucidated.

It is easily conceivable that pressure, exerted by the growing roots

Nikolsky ( ) advanced the hypothesis that the main factors determining the formation and stability of aggregates in chernozems are the roots of living plants and the undecomposed residues of dead plants. The root hairs serve to bind mechanical elements together and the humus produced by enhanced biological activity of the rhizosphere cements the more finely divided particles - the first stage of aggregate formation. The next stage is the formation of water-stable mass under the influence of humus and adsorbed calcium and its simultaneous break-downinto granules by the action of root pressure, temp. change, etc., When cultivated, the aggregates remain stable only as long as decomposed plant residues are present to bind the mechanical elements together and the humus is saturated with Ca.

Sekera and Brunner ( ) maintain the microscope shows that whereas the smaller aggregates are composed of particles bound by colloidal elements, the larger aggregates are held together by living matter - root hairs, fungal mycelia, etc., Actual structural stability is the sum effect of these colloid-chemical and biological factors.
A deficiency in the biological factor leads to a structural breakdown into smaller aggregates and a deficiency in the colloid-chemical factor to a more or less complete peptization.

As Baver ( ) states, it seems plausible to conclude that something comes from the plant root that stabilises any aggregate that is formed, irrespective of the mechanism of this formation.

2. <u>Microbial Activity</u>: The majority of microbiologists subscribe to the view that mucilaginous or gummy polysacharrides produced extracellularly by many bacteria may have a cementing action. These might well be utilised in turn by other organisms, so that the effects produced by them would not persist.

Martin ( ) suggests that some of the organic aggregating agents released from decomposing organic residues by the soil organisms may be resistant to microbial decomposition or they may unite both physically and chemically with the soil colloid particles and the humus and thereby be rendered resistant to further change. On the other hand, as evidenced resistant complexes. During the decomposition process it is very probable that soil aggregating substances are continually being produced and destroyed by the changing microbial population.

Martin and Waksman ( ) also refer to the influence of fungal mycelia stating that much, but not all, of the binding effect in aggregate formation was due to fungal mycelia enveloping the soil particles, but disappeared when these were broken up. This cause of unstability was also recognised by Mishutin ( ).

Much support has been given in Russia to W.R. Williams' views that the origin of active humus is the root system of perennial grasses and that humus itself is a synthetic product of rhizosphere-inhabiting bacteria. It is not the organisms themselves that are responsible for aggregation but autolysis products and other products produced by certain organism when utilising previously synthesised microbial tissue.

Grasses characteristically have extensive fibrous root systems ( ). The roots of perennial grasses have the composition of mature tissues and are continually dying and being replaced, thereby providing a continual source of energy material in addition to sloughed-off epidermal cells and root excretions. The activity of rhizosphere bacteria, enormous in numbers sheathing the ramifying fibrous root system of a grass and utilising the roots and rootlets as they die, may cause the most desirable stable structure produced under sod. If this is the case, then the simple process of turning under crop residues, even in large amounts, is likely to be far less effective than a sod in causing improvement in aggregation. This has been borne out by experiments in the field where the greater persistence of effects following sod are evident. Geltser ( ) agrees with this statement and believes that rhizosphere bacteria are mainly responsible for the increase in soil aggregation during the growth of a grass crop. The activity of the rhizosphere bacteria depends on the density of the root system. When the sod is ploughed up further aggregation may take place by the bacterial decomposition of the plant residues. At the same time,

loss of structure

ditions. It has also been shown that the structure of the subsoil of grassland in which anaerobic conditions prevail, persists much longer than that of the surface soil.

Nevertheless the formation of mucilage is an aerobic process ( ) and in general more mucilage is produced the more rapid the decomposition. For this reason Geltser maintains that the more rapid decomposition of cellulosic material e.g. green manures, than of ligneous materials (stable manures) give the former an advantage as structure formers.

Of the chemistry of the bacterially-synthesised humus little is known, but a crystalline substance believed to be allantoin - has been isolated from the products of autolysis. Here lies a possible correlation with the allantoin of animal urine - both probably significant in improving the structural nature of soils.

Undoubtedly our knowledge of the part that micro-organisms play in affecting the physical properties of the soil is far from complete and offers a fertile field for futher fundamental research.

3. Type of Cover: Many workers have shown that a grass cover and to a lesser extent, a close-growing leguminous crop, has a marked effect on increasing the aggregation of the soil. On the other hand, structure tends to deteriorate under row crops as a result of intensive cultivation.

Rostovzeva and Avaeva ( ) proved most conclusively that deteriorated structure could be regenerated by means of grass vegetation. Martin ( ) however found there was considerable variation between them. The formation of crumb he considered was dependent on the amount of clay in the soil and therefore even the best grass rotation could not be expected to be beneficial on soil of very low colloid content. Sarakhov ( ) who investigated this variation between species states that perennial grasses assist the formation of stable soil structure, whereas annual grasses pulverise the soil and destroy its structure. During this first year perennial grasses have more effect on the soil structure than do leguminous plants and although clovers do have a positive effect in their first year there is scarcely any in the ensuing years. The contrary is true of lucerne.

micro and macro-structure of the soil after clover and lucerne, compared with the rapid breakdown of the soil granules on land cropped to cotton. However, according to Vorob'eva ( ) it was the combination of both legume and grass that was most effective in building the most desirable soil structure.

Another aspect is the actual coverage of the soil by the crop. Deterioration of structure, through dispersion of the surface soil, resulting from the impact of raindrops, is prevented by the vegetative foliage. The detrimental affect is on the large pores rather than in the of total porosity i.e. a decrease in the content of large pores and increased compaction. ( )

It appears that those crops which provide more cover and have a more fibrous and extensive root system have the greater effect upon soil granulation.

4. Lime and Manure: The direct influence of lime upon soil aggregation has now been proved insignificant. Nevertheless investigators agree that indirectly its influence is unquestionably beneficial.

Browning and Milam ( ) from their detailed study on soil aggregation, concluded that the indirect effect of lime on microbial activity and plant and root growth was a very important factor in the development and maintenance of a desirable soil structure.

Geltser ( ) in her revolutionary thesis on humus formation, which postulates a biological rather than a chemical concept, maintains that the role of lime in the formation of soil structure is not physico-chemical. The flocculation of soil colloids she affirms is incidental to the main role of creating conditions favourable for the bacterial synthesis of active humus.

According to Baver ( ) the effects of manure on soil structure are far from clearly understood and considers that it exerts a favourable effect upon granulation and aeration in the soil which is only temporary.

The Russian worker Sokolovsky ( ) has also recognised its complexity - the possibility of a dispersive action on soil aggregates owing to the

The influences are considered to be dependent somewhat upon the season and the type of soil.

In the experiments conducted by Rubashev ( ) he found that although manure was an essential factor for the improvement of soil structure, the simultaneous use of both manure and clover was even more effective in increasing the water-stability of aggregates. A seasonal variation was also noted in the number of these aggregates, the lowest amount being present in the spring.

Elson ( ) also reports that fertilised and manure-treated plots had 8% more macro-aggregates than untreated, while manured plots had 15% more than fertilised.

Nevertheless, with the possible exception of heavy applications, the fertility factor usually outweighs the physical advantage obtained from added manure, and Baver ( ) concludes that applications of manure to grassland benefits structure indirectly, that is by increasing the growth of the structure-improving plants.

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The forms of phosphorus occurring in the soil can be conveniently divided into the following categories:

(a) Inorganic Phosphorus (i) Mineral Phosphorus

(ii) Adsorbed Phosphorus

(b) Organic Phosphorus.

The mineral phosphorus present in soils consists of a large variety of phosphate-complexes ranging from those of the original source, e.g. as in apatite to those of a secondary nature, e.g. Ca, Fe and Al phosphates; the adsorbed phosphorus fraction refers to the ionic phosphate held by the colloidal particles in the soil and considered susceptible to the ionic exchange phenomenon; the organic phosphorus compounds occur in the organic matter fraction of the soil, being present in plant and animal residues and products of microbial synthesis. ( )

Although copious literature has been written relating to the forms and fixation of phosphorus in the soil, comparatively little is known of the availability of these various forms to the plant. An attempt was made in the present investigation to measure, by chemical method, the influence of pasture, lime and manure on the amount of available phosphorus in the soil and to examine the relationship existing between the available phosphorus present in the soil and that taken out by the herbage.

The uptake of phosphorus from the soil by pasture varies not only with the yield but also with the composition. For instance, grass withdraws more phosphorus from the soil than clover. Pedigree New Zealand white clover growing at its best at Palmerston North will give a total annual yield of some 10,000 lbs. of dry matter per acre, containing on the average 0.8% P_2O_5 and 5% nitrogen. Ryegrass growing at its best will give a yield of some 15,000 lbs. of dry matter with an average of 1.0% P_2O_5 and 3.5% nitrogen. ( ).

The influence of lime on phosphorus availability in the soil is indirectly reviewed by Truog ( ) in his recent paper discussing soil reaction in relation to nutrient availability and where he reaction to be about the pH 6.5 level where the calcium bicarbonate becomes sufficiently abundant in the soil solution to keep a considerable portion of the phosphorus in the form of calcium phosphate which is soluble in carbonic acid and therefore he states, readily available to crops. From an investigation by Gardner and Kelly ( ) on the relation of pH to phosphate solubility in soils, they found that if the solubility of phosphate is very low within the pH range of the soil solution, a low availability can be expected unless there is at the same time an available supply of exchangeable phosphate ions attached to the colloid sufficient to meet the plant needs. They consider, in other words, that the solubility of phosphate in the pH range corresponding to the probable range at field moisture is closely related to plant available phosphate.

Engel ( ) reported the increase in the "root solubility" of the soil P_2O_5 produced by lime as varying widely and that no definite relationship could be established between the degree of reactivity and the increase in solubility resulting from the application of lime. Hester ( ) even found that lime caused a depressive action upon phosphorus solubility due however in this case to the maximum solubility of the phosphorus-fixing Fe and Al compounds at the particular pH produced by the addition of lime.

Dean and Rubins ( ) in one of their discussions on adsorbed phosphorus made the statement that the concentration of the soil solution in respect to phosphate ions and the rate at which this concentration is maintained is a function of the pH, exchangeable phosphorus and anion exchange capacity. The presumption was that these are the factors which influence the availability of exchangeable phosphorus and consequently offers an explanation why liming increases the availability of phosphorus in soils.

Dunn (26) from his studies on Washington soils concluded that lime applications within practical limits are beneficial, particularly between pH 6 and 7, because they increase the availability of soil phosphorus and the supply of calcium for plant nutrition.

to plants is obviously in doubt, although results tend to support the affirmative.

The influence of manure on the phosphorus supply in the soil is derived mainly from the dung fraction, returning as much as 400 lbs. P_2O_5 /acre on high producing pasture ( ). However as to its actual availability there is some doubt. Ghani ( ) in a fractionation of organic manures found that 75% of phosphorus in farmyard manure was inorganic and most of it easily available, whereas in compost, although similar, it was difficultly available. Metzger ( ) also reports from an investigation of 27 years duration, that in general, phosphorus applied in manure was largely utilised by the plants and little accumulated. Gericke ( ) however, considered the phosphorus in rotted manure to be less available than that in basic slag, and quotes the figure of 17% for available phosphorus present in the commercial fertiliser and 14% for that in manure. Regarding its effect on the insoluble phosphorus fraction of the soil, Routeberg ( ) found no evidence to prove that the availability of the latter was influenced in any way.

The indirect effect of manure on phosphorus availability through its influence on the organic matter content of the soil also requires consideration. Laatsch ( ) considered that the reduction in the phosphate fixing capacity of a calciummontmorillonite when treated with a neutral solution of potassium humate, was due to the saturation by humic acid of the positive, residual valencies of the mineral lattice. Dunn ( ) in his studies, attributed the increase in phosphate fixation below, and decrease above pH 6, when organic matter was removed from several soil colloids, to the removal of the organic matter coatings around the particles of Fe and Al compounds. Metzger ( ) ascribed a reducing action to organic matter which he suggested partly accounted for the greater availability of phosphorus in the surface layers as compared with that in subsoils, i.e. it may maintain a portion of the phosphorus in forms more readily available to plants. An interesting investigation into the effects of the combination of phosphate with farmyard manure on the availability of the former was made by Midgley and Dunklee in 1945 ( ) who reported that there was phosphorus into less soluble but slowly available organic compounds and also to revert monocalcium phosphate to hydrated tricalcium phosphate which in the freshly precipitated moist condition is quite available to plants and not subject to further fixation.

It appears therefore, that the available soil phosphorus is significantly increased by the application of farmyard manure and as a constituent of the soil organic matter also plays a beneficial role in phosphorus availability. Its influence on the insoluble phosphorus reserve already present in the soil, however, is not well established.

THE POTASH IN THE SOIL.

Under permanent pasture conditions and efficient stock management, North Island soils seldom exhibit a potassium deficiency; in fact, many of the high producing swards that annually drain large quantities of this nutrient from the soil, continue to maintain a high level of production without adequate replenishment, for many years. The large amounts of available and temporarily unavailable potassium stored in some soils is well demonstrated in the present pasture trial ( ) where the available potash supplied by the soil to the plant has reached to date, an amount equivalent to over 1000 lbs. K_2O and is still continuing to supply this element entirely from soil reserves. Investigations into the influence of lime, fertiliser and manure on potash fixation and availability have received considerable attention overseas where such deficiencies are a serious problem. Much of the advanced knowledge relating to the mechanism involved in potash fixation in the soil can be attributed to the comparatively recent work of such men as Martin and Overstreet, et. al. ( ) and Attoe ( ) of America and Joffe and Levine ( ) of Hawaii.

In regard to the influence of liming on soil potash, Roger and York ( ) noted that its effect depended upon the supply of non-exchangeable but slowly available potash in the soil and the capacity of the soil to adsorb bases. Liming sandy and silt loams caused a definite increase in the fixation of potash whereas the potassium released from clay loams was little affected and in some cases relative base saturation of the exchange complex. This repression in release of potassium, which Attoe ( ) noticed, when acid soils were limed, was nevertheless beneficial because it retards and prevents an extravagant consumption of this element by plants. He also found that when potassium chloride was added to the soil at the rate of 90 lbs. K/acre, it was fixed in amounts ranging from 12 - 59%. Apparently this fixed potash became available to a considerable degree as required.

Wrenshall and Marcello ( ) undertaking pasture studies, reported that when superphosphate was added with potassium the available potash in the soil was significantly less than when potash was applied alone, due partly to the greater uptake of this element by phosphate-fertilised pasture and also to the fact that inorganic constituents are responsible for fixation in a non-exchangeable form which is promoted by soluble phosphate.

From this brief survey it appears that liming tends to increase fixation of potash in the soil as also does the addition of fertiliser. However this fixed potassium is not entirely unavailable but appears to be partly retained or stored in the soil for use by plants as required or in endeavouring to maintain a constant equilibrium between exchangeable and non-exchangeable soil potash. ( ).

The contribution made to the potassium level of the soil by the addition of animal manure, was revealed through the work of Sears ( ) to be of real significance. On high producing pastures yielding 12,000 lbs. dry matter /acre/annum, the animal returns, mainly through the urine, an amount of potash equivalent to 700 lbs. K_2O annually. Rich and Obensham ( ) examining the influence of farmyard manure on the exchange complex of the soil recorded not only that the exchangeable potassium was increased, but also the exchangeable calcium, exchangeable magnesium and the cation exchange capacity of the soil.

When investigating the effect of organic matter on the potassium mineral portion of the soil, i.e. blocking fixation with large organic molecules. Wersham and Sturges ( ) working with Mississippi-delta soils also noticed that the addition of organic matter not only increased the leachable and the available potash, but, on fine sandy loams very responsive to this element, also changed more than 70 p.p.m. of native potash from the non-exchangeable to the exchangeable form.

An interesting paper by Hurwitz and Batchelor ( ) on the biological fixation of potash, presents some interesting and thoughtful results and conclusions, viz. that more than 50 lbs./acre of potash can be held by soil micro-organisms; the possibility of competition between plant and organisms for other soil nutrients; that this fixation does not appear to be harmful to plant growth. Further studies should prove extremely interesting in attempting to evaluate the extent and true importance of biological potassium competition.

AMMONIA AND NITRATE NITROGEN IN THE SOIL.

It is considered that the most available forms of soil nitrogen occur in the ammonia and nitrate condition. According to Krantz ( ) the ammonium cations are rather immobile in soil while the nitrate anions move freely with soil moisture, therefore it would appear that the nitrate form is more readily absorbed into the plant. Nevertheless it is a well known fact that plants, especially when young, readily assimilate the ammoniacal form. Mature plants, also, when nitrification is at a minimum, are sometimes forced to use this form and apparently quite satisfactorily.

Krantz ( ) experimenting with Indiana soils found that when sulphate of ammonia was ploughed under, much of the applied nitrogen remained in ammonium form in the moist root zone throughout the growing season. In the case of topdressed sulphate of ammonia, it remained on the surface of the soil and was completely unnitrified after 24 dry days. Even after heavy rains practically no ammonium moved below the 3" level in the silt loam soils examined.

when the temperature reached 85°F. or above. Below this temperature there was no loss when the soil was at optimum moisture content. However when the soil was flooded, ammonia nitrogen was lost through flood waters over the entire temperature range and in this case influenced by soil reaction - the most alkaline soil suffering the greatest loss.

Nitrate nitrogen appears to move more freely in the soil. Schofield ( ) found a high positive correlation to exist between rainfall and the leaching of nitrate nitrogen from the surface 6" to lower layers of soils.

The influence of temperature on nitrate movement has shown that there tends to be a summer accumulation period ( ) when thenitrate nitrogen moves upwards in the soil to collect in the surface ½" ( ) Matthews ( ) also reported that during hot weather which completely dried the upper few inches of soil, most of the soil nitrate came to or near to the soil surface. Similarly the formation of nitrate in podsols under different kinds of cultivation examined by Nikolic ( ) revealed that both in soils planted to legumes and in fallow land, a definite maximum in nitrate formation occurred in the spring. Even in untilled pasture land which remained constantly low, this peak of nitrate content was also apparent in the spring/summer period. According to Matthews ( ) this form of nitrate nitrogen is unavailable to crops and readily lost by sudden hard rain causing run-off or by blowing, particularly if stock are allowed to trample or root.

Bizzell ( ) discovered that when pasture, mainly timothy, was grown continuously and nitrogen applied as Nitrate of Soda, the drainage contained only very small amounts of nitrogen regardless of the quantity of fertiliser used. The nitrogen content was approximately the same in the soil from the beginning to the end of the experiment, due to "loss by volatilisation". This fact is probably of real significance when one considers the quantity of nitrogen returned by way of the animal excreta, especially the urine.

Sears ( ) realized the possibility of such losses when investigating various methods of returning animal excreta to the pasture and this dissipation of nitrogen and suggested numerous methods and techniques to prevent or reduce the loss.

The use of legumes as savers of nitrogen has been a recognised practice in crop rotations throughout the world for many years. Similarly in New Zealand today the use of clovers in pasture establishment and maintenance is considered by all progressive farmers of paramount importance. An indication of their value is given by Sears ( ) when he states that a good stand of pedigree white clover will abstract nitrogen from the air equivalent in amount to that contained in one ton of sulphate of ammonia per annum. Consequently the resultant benefit to the nitrogen status of the soil and associated plants from such a storehouse either directly or indirectly can well be imagined.

In a large number of the papers reviewed, investigators found tremendous variability in ammonia and nitrate determinations and therefore difficulty in obtaining conclusive results. For instance, Karraker ( ) discovered that although the field was quite uniform, variability in the analyses was considerable, the greatest variability being associated with the greatest amount of nitrate present. Blaney and Smith ( ) sampling market-garden soils and Davies, Coup et. al. ( ) analysing Waikato pasture soils were confronted with the same problem. In the latter investigation, samples that were taken from spots only inches distant displayed marked differences, suggesting that there were pockets of high and low nitrate in the soil even where the pasture appeared most homogeneous.

As a source of nitrogen the urine portion of animal manure is of greater importance than the dung, as demonstrated by Sears ( ). He found that the urine returned to a "14,000 lb. dry matter pasture" contained nitrogen equivalent to that contained in 1045 lbs. sulphate of ammonia while the dung returned nitrogen equivalent to that contained in only 468 lbs. sulphate of ammonia. Wested and Iversen ( ) however, considered that due to the large volatilisation losses of nitrogen from the urine and consequently an extremely variable effect on the soil nitrogen, the more significant and permanent value of "available nitrogen" level under pasture rocketed from a few to several hundred parts per million on the urine spots. The quantity contained in this liquid fraction was also well emphasised from their study of sheep urinations; where a single sheep urination was found to add nitrogen to a soil patch at the rate of approximately 1,000 lbs. nitrogen/acre as compared with addition through pasture of approximately 30 lbs./acre in 2 weeks plus roots, which add much less.

Further investigation by these workers ( ) showed that the increase in nitrate after urine was artificially applied was not very conspicuous till 2 - 3 weeks after application, the maximum being reached in 4 - 6 weeks, i.e. ranging from 30 p.p.m. after the first week to 117 p.p.m. in the sixth week and back to 69 p.p.m. in the seventh week. Ammonia nitrogen however came to a maximum within the first week and then gradually declined.

In normal Waikato soils the ammonia and nitrate nitrogen content in the majority of analyses ranged from 1 - 20 p.p.m. although, as stated, urine patches soared to several hundred p.p.m. Normal soil samples usually have less than 40 p.p.m. of available nitrogen which is in agreement with Blaney and Smith ( ) who considered the figure generally lay between 20 - 40 p.p.m.

According to Ashworth ( ) the available nitrogen fraction of the soil, represented by the ammonia and nitrate form, amounts to 5 - 15% of the total nitrogen present. His figure for soils under permanent pasture covering a depth of 0 - 10 cm. was approximately 6.7%.

ORGANIC MATTER IN THE SOIL.

According to Millar and Turk ( ) changes in organic matter content of soils attributable to manure are affected in two ways; the actual residue of the manure applied; the contribution by the roots and stubble of the increased crop produced by the manure. The value of farmyard manure for conserving soil humus and nitrogen depends to a large extent upon the crops used in the rotation. If used on cultivated crops such as potatoes or tobacco the gain from increases in roots and stubble residue may be very small, but with to an optimum level, is well known to the Russian workers and in many crop rotations of America its inclusion is an absolute necessity for the maintenance of soil productivity.

Directly associated with the soil organic matter content is the water-holding capacity of the soil Chen ( ) for instance recorded the fact that the moisture-holding capacity and pH of the soils investigated, increased with increase in the amount of manure added.

The liming of an acid soil results in significant effects on the soil organic matter by stimulating the activity of the general-purpose soil organisms and consequently the rate of turnover of the organic matter. According to Lyon and Buckman ( ) this stimulation of enzymic processes not only favours the formation of humus but also encourages the elimination of certain organic intermediate products that might be toxic to higher plants. A similar microbiological response was observed by Maiwald ( ) after the application of dung to soil, which is possibly due largely to its calcium content.

Apart from the small quantity of organic matter supplied by the organic fertilisers, the influence of fertiliser application on organic matter maintenance is also indirect ( ). By increasing the supply of available plant nutrients and later the plant residues the rate of organic matter accumulation and humus formation under pasture is also increased. Although present-day methods of farm management are demanding a more intelligent consideration and utilisation of the manure produced on the farm, it must be remembered that the amounts of the essential elements contained per ton of farmyard manure are comparatively small and it is only because of the large acre applications of this manure that the quantities of nutrient elements added are so significant ( ). Consequently most authorities regard manure as a means of aiding in the maintenance of the soil organic matter supply rather than as a means of increasing it. As Lyon and Buckman ( ) state, "it is only when farmyard manure is properly co-ordinated with lime, commercial fertiliser and legumes as well as with good tillage, weed elimination

till approximately 1945, consisted almost solely in the classical publication of Darwin's (1881) "The Formation of Vegetable Mould through the Action of Earthworms". When A.C. Evans (2) of Rothamsted commenced investigations of earthworms in 1945 his own words were "I was astonished at the small amount of knowledge available on these common creatures; not even the bare outlines of the life-cycle of even one species was known." Within the last four to five years, however, there has been an outburst of interest by both the research worker and the commercial speculator resulting in the greater attention that is now being given to these lowly organised creatures. Because of this present-day interest and the actual lack of research relating directly to the present investigation, the liberty has been hesitantly taken in reviewing the literature over a slightly wider field in connection with earthworm influence on soil structure.

Although present in almost all soils, earthworms abound in heavy soils and are especially plentiful in old lawns and grasslands where the organic matter is considerable and the moisture abundant. (6)

They feed partly on soil, digesting organic matter both animal and vegetable, and partly on green material, mainly leaves, which they drag into their burrows and consume.

The species of earthworm found most commonly in soils are as follows:

Allolobophora	longa	
"	nocturna	
"	caliginosa	
"	chloretica	
Octoclasium	cyaneum	
Lumbricus	terrestris	
"	rubellus	
Eiseniella	tetraeda	
Eisenia	foetida)	found mainly in compost heaps
"	rosea)	and suchlike environment.

species appear to be:

Allolobophora caliginosa

Lumbricus rubellus

which was in agreement with present findings.

Considerable variation in the species distribution has been found throughout countries due mainly to varying levels of fertility occurring under different soil types and soil treatments. For instance, Evans and McL. Guild (5) noticed that permanent pasture fields showed a high percentage of Allolobophora nocturna and a lower percentage of A. caliginosa. Ploughing old permanent pasture and reseeding to grass after 1 - 2 years of cultivation reduced the proportion of these two species and increased Eisenia rosea. Under arable conditions, A. chlorotica was found to be the dominant species.

A comparison of species taken from Rothamsted and the Carse of Stirling (Scotland) presented further evidence of the influence of soil type on earthworm distribution, as the dominant species occurring in pasture land at Rothamsted was not even found at Stirling.

EARTHWORM POPULATION.

The difficulty of obtaining accurate estimates of the worm population in pasture and arable land is due to the sampling technique. Many methods have been tried and discarded without any real success. The most popular appears to be the "Permanganate Method", where ½ oz. of $KMnO_4$ dissolved in one gallon of water is applied per square yard of surface. Although realising that soil temperature and moisture affected the proportion of the total population brought to the surface with this method, McL. Guild and Evans ( ) nevertheless found it very useful for comparative estimations between different fields or on the same field from time to time. Thus the numbers extracted, although probably below the true total, were accurate comparatively.

Morris ( ) estimated one million worms /acre on a farmyard manure plot at Rothamsted and half a million /acre on a plot which had received no manure for eighty years. Baweja ( ) however calculated the worm population under pasture at three million /acre which he states "is as many as 600,000 - 750,000 worms /acre was ploughed ( ) there followed after the first year, in which there was little change, a rapid decline in population to approximately 100,000 worms /acre within five years, due apparently to a reduction in food supply. Lower fertility arable and ley areas displayed even fewer worms and all of a smaller species. Similarly, when an acid hill pasture containing approximately 52,000 individuals / acre, mostly of a small species rarely found in good pastures, was ploughed, limed, given fertiliser treatment and reseeded to grass, the earthworm population increased 300 - 400%, the increase chiefly consisting of species usually associated with good pasture. He found that on farmlands the highest populations were on light loams and lowest on clays and gravelly sand.

SEASONAL ACTIVITY.

Evans ( ) when investigating the life-cycles of earthworms, noticed that cocoons were not produced all the year round by all species. In the case of two, Allolobophora longa and A. nocturna, an obligatory rest period or diapause occurred during the summer months when they were rolled-up in a tight ball in a spherical earthen cell, this stage being broken when the soil moisture reached 20% in the early autumn. A. chlorotica, A. caliginosa and E. rosea underwent a facultative diapause only when soil conditions were unfavourable, for example, during the dry spells in summer and cold periods in winter. Species of the genus Lumbricus were never found in diapause but reached depths of three to five feet when surface conditions were unfavourable, indicating a movement up and down with climatic variation. Dowdy ( ) also noticed this vertical migration, the critical temperature being around 42°F. It seems that when surface temperature approaches freezing point, a very slight change might exert a very great influence upon the depth of the organism in the soil. However, the tendency for worms to return deeper in the soil during the spring he attributes to lack of moisture.

It appears that there is a definite seasonal trend in earthworm activity influenced in the main by soil temperature and soil moisture, progresses, further activity appears to fluctuate closely with soil conditions, that is, the unfavourable soil temperature and moisture conditions of winter cause an increasing decline, as the weather deteriorates to its mid-season limit. With the improvement in the environment associated with early spring, the worms once more commence their more active life which in this case is halted in the late spring by the oncoming dry period. The peak of activity reached in the spring never appears to attain that reached in the autumn and the limiting factor in this case is attributed more to soil moisture conditions. Although the various species show expected individuality in their capacity to withstand and respond to varying soil conditions, they all appear to follow much the same seasonal cycle.

Only two species, A. longa and A. nocturna, were observed by Evans ( ) to produce surface casts, all other species apparently excreting the soil which they consumed into air spaces below the soil surface.

This casting habit is fully appreciated by greenkeepers who apply heavy applications of acid fertiliser annually in an endeavour to prevent damage to the "greens" through worm activity. However, soil reaction "per se" has little to do with earthworm distribution according to Allee ( ) who considers there may be rather indirect effects of pH upon worms through its influence on the physical conditions of the soil and soil flora. He noticed that A. caliginosa and L. rubellus tolerated a wide range of pH, the former being the more tolerant. In general, slightly alkaline soils seem a more favourable medium than acid soils, which is in agreement with Olson ( ) who found worms most abundant at pH 8 although they occurred over a pH range of 4.5 to 8.7.

Only three species were observed ( ) on the surface at night, A. longa, A. nocturna, and L. terrestris, and only the latter seen mating on the surface. Most species apparently mate underground or inside the compost heaps.

It is worthy to bear in mind that many of these variations may be caused, in part, by such factors as differences in breeding season,

EFFECT ON SOIL PRODUCTIVITY:

(i) CHEMICAL AND BIOLOGICAL.

The beneficial chemical and biological effects that earthworm activity has on the soil is directly associated with the thorough mixing and thorough digestion of the plant material with the soil. As Lunt and Jacobsen (12) and Puh (13) concluded, it is both the mechanical mixing and the action of the digestive secretions favouring the decomposition of the organic matter and the soil minerals, that causes the increase in exchangeable nutrients. Through the action of their casting habit, exchangeable calcium, potassium and magnesium increases, available phosphorus and pH rises and there is a higher value for total and nitrate nitrogen.

Russell ( ), Heidermanns ( ), Bates ( ) and Lindquist ( ) also recognised their favourable effect on soil nitrogen, but Russell considered that it was the dead rather than the live worms that were so important to crop yields, due to their content of 10 mg.N/worm which on death and decomposition constituted a significant nitrogen fertiliser. Recently however, Hopp and Slater ( ) contradicted this hypothesis. The soil used in their experiment was unproductive by all standards of fertility, yet when living earthworms were introduced and favourable cover conditions were maintained, the vegetation grew luxuriantly. Where only dead worms of an equivalent number were introduced, the vegetation was relatively poor both with and without cover condition normally favourable for the over-winter development of earthworms.

Dutt ( ) although recognising the improvement in the physical condition and the increase in chemical nutrients of the soil, considered the worms' main benefit lay in the associated stimulus to bacterial activity through improved drainage and aeration.

Worms therefore contribute to nitrification in the soil not only through the decomposition of their own bodies but also by their living action of mixing organic matter with mineral soil and stimulating bacterial activity.

transformation of organic matter in the soil, earthworms being the most active humus formers. Meyers (28) in 1943 also found that the passage of organic material through the bodies of the worms greatly influenced the process of humification, the excrement containing 50% true humic acid whereas the rotted straw contained only 18% in a much less advanced stage of decomposition; the C/N ratio 10 as against 18; the ash content 65% as against 6.8% in the rotted straw. Consequently, though the amount of humification per animal may be small, the total numbers of such soil fauna are often very high andmay account for a considerable proportion of the humus produced.

(ii) PHYSICAL

Darwin ( ) was the first to present figures on the amount of earth pushed up by worms in one year. His estimate of 8 - 16 tons/acre /year is probably somewhat excessive according to Evans (2) who considers it in the vicinity of 10 - 12 tons/acre/annum, varying however from 1 - 2 tons on leys one to seven years old up to 25 tons on three hundred year old pasture. The record estimate of 107 tons/acre/annum occurred in the valley of the White Nile, Sudan.

Worms do not swallow particles of soil larger than 2 mm. in diameter, thus the production of wormcasts over a period of years results in a layer of fine stone-free soil varying in thickness from 4 - 8", which is commonly found on well-established pasture land. Such a depth distribution of stones was observed by Evans (2) on two fields at Rothamsted, one a seventy year old pasture, the other a seven year old ley following many years arable. The casting activity of the worms over the seventy years had brought about a considerable reduction in the weight of stones in the top 4" and an increase at 5 - 8" whereas their action in the seven years ley had not caused any measurable change.

In 1942 Sir Arthur Keith (19) added a postscript to Darwin's work after re-examining the original fields referred to in "Vegetable Mould through the action of the Earthworm". His conclusion, from observing the effects of a further sixty years of earthworm activity, and there abide.

Lunt and Jacobsen (12) from their investigations on the influence of earthworms on soil aggregation and porosity, considered that, although some workers had the opinion that earthworms followed fertility, there was sufficient evidence to definitely prove that worms improved soil structure by increasing the aggregate content and porosity of soil thus facilitating aeration, water absorption, root penetration and drainage. Hopp (20) in his experiment using fine-seived soil with and without earthworms, discovered that in three days the percentage of large aggregates (2-3 mm. diameter) in the two treatments were 12 and 5.9 respectively. Species also displayed variation in aggregating ability, for instance, L. terrestris produced the biggest aggregate in the shortest time, due presumably to its larger size, while A. caliginosa and E. foetida produced smaller aggregates at a slower rate. He concluded by suggesting that an adult earthworm under favourable conditions may produce 1 gm. or thereabouts of aggregates 2 - 3 mm. in diameter per day. Gurianova (21) from a similar experiment considered their beneficial effect on the structure of pulverised soils to be especially in the 0-1 mm. fraction.

In addition to building "crumb" structure in the soil the water stability of each individual crumb is also strengthened. Hopp and Hopkins (22) working with unsterilised field soil, found that the aggregates from cultures containing no earthworms were 4.47% water-stable, while those formed by earthworms were 15.68% water-stable after a period of four days. Hopp (20) by using the McCalla Drop Technique (23) also showed that it required 6 drops of water to disintegrate an aggregate of the "no-worm" treatment, whereas 13 drops were required to disintegrate a "worm-treated" aggregate.

Much of the agricultural land consists of fine-textured soils, as in the experiment of Slater and Hopp (17), and it is on these soils that decline in structure is widely recognised as an important problem. It is here that earthworms, being such a factor of significance to free layer of fine soil which at the same time causes stones, etc. to subside; they actually pull the dead leaves, etc. into their burrows for later consumption. It is in this way that the formation of a thickly entwined surface mat, which would quickly kill out the finer grasses, is prevented ( ). Evans' hypothesis, as to the usefulness of earthworms, therefore emerges from a rather different avenue of investigation with less appreciation of their structure-forming ability. He concludes that on arable land where machine cultivation opens up the soil and buries organic residues for bacterial decomposition, the role of the earthworm is comparatively unimportant, but on permanent pasture they probably perform many valuable functions, burying and decomposing organic matter and keeping the soil aerated and well-drained.

There has been some controversy over the various methods of measuring aggregate-size distribution regarding the "speed of wetting" of the sample. Smith and Browning ( ) for example consider that rapid wetting of the soil samples does not give an accurate interpretation of the stability of the crumbs due to "explosive destruction" caused by the sudden compression of the entrapped air. For the same reason however Sekera and Brunner ( ) recommend that structural stability should be measured on rapidly wetted samples whereby differences in stability are most clearly shown. In this experiment, the technique adopted was the rapid wet-sieving process devised by Bouyoucos ( ).

G.J. Bouyoucos has been a very prominent figure in this field and from his early work showed that when soils in the dry and field condition were placed in an excess of water they disintegrated and slaked into particles or granules of various sizes. The slaked product represented the ultimate natural structure of the soil because they appeared stable and required the application of external energy and dispersing agents to break them up further, and so in 1935 he suggested a "wet-sieving" method whereby this ultimate natural structure of soils could be measured.

Owing to the type of soil structure being dealt with, that is, the very high root content under high producing pasture, it was found necessary to modify the method slightly.

(a) The personal element associated with the Bouyoucos ( ) method incorporated excessive error and necessitated the investigation and finally the adoption of a mechanical shaking device which removed the personal factor and consequently gave more accurate results.

(b) The inclusion of a preliminary sieving through a coarse-mesh sieve (No. 5 I.M.M.) which proved effective in removing the interference of the large roots and resulted in the true aggregate being obtained.

The material and apparatus required for the determination included the following:

(a) The sample consisted of 50 gms. of air-dried soil preferably in small lumps of 3 to 5 gms.

(c) Two specially-constructed pans sufficiently deep to hold the required water and sufficiently wide to cope with the "stroke" of the mechanically-driven sieve.

(d) A piston like arm driven from a pulley, to provide the required gentle motion - approx. 1 stroke/sec. i.e. forward and back every 2 secs.

Photo.

Photo

The Method: Used.

50 gms. of soil was weighed and placed on the No. 5 I.M.M. sieve in one of the trays, covered with distilled water and allowed to slake for approx. 24 hours. The material was then given a preliminary shaking, the clinging effect of the larger roots being carefully prevented by hand until all the soil had passed through i.e. particles bigger than 4m.m. (No. 5 I.M.M.) not being considered as true aggregates.

aggregates smaller than 2 m.m. diameter passed through, the larger particles remaining on the sieve. This process was repeated separately and carefully for each sieve. The sieves were then put in the oven at 110oF and after drying their contents were removed and weighed.

All the material that went through the finest sieve used - No. 100 I.M.M. - was collected in a large beaker and later mixed with all the "separates" after weighing. This mixture was then dispersed and again passed through all the sieves to ascertain the amount of sand that might have been counted as granules and if necessary the results adjusted accordingly.

All analyses were carried out in triplicate.

The Plots Sampled: A brief preliminary investigation was carried out to determine the method of sampling that should be adopted to record the visual differences. This resulted in the sampling of four selected plots at different depths, any additional choice being prevented by the volume of work involved.

The plots selected for investigation were:

Grass alone without added Manure

Grass + Clover without added Manure

Grass alone with added Manure

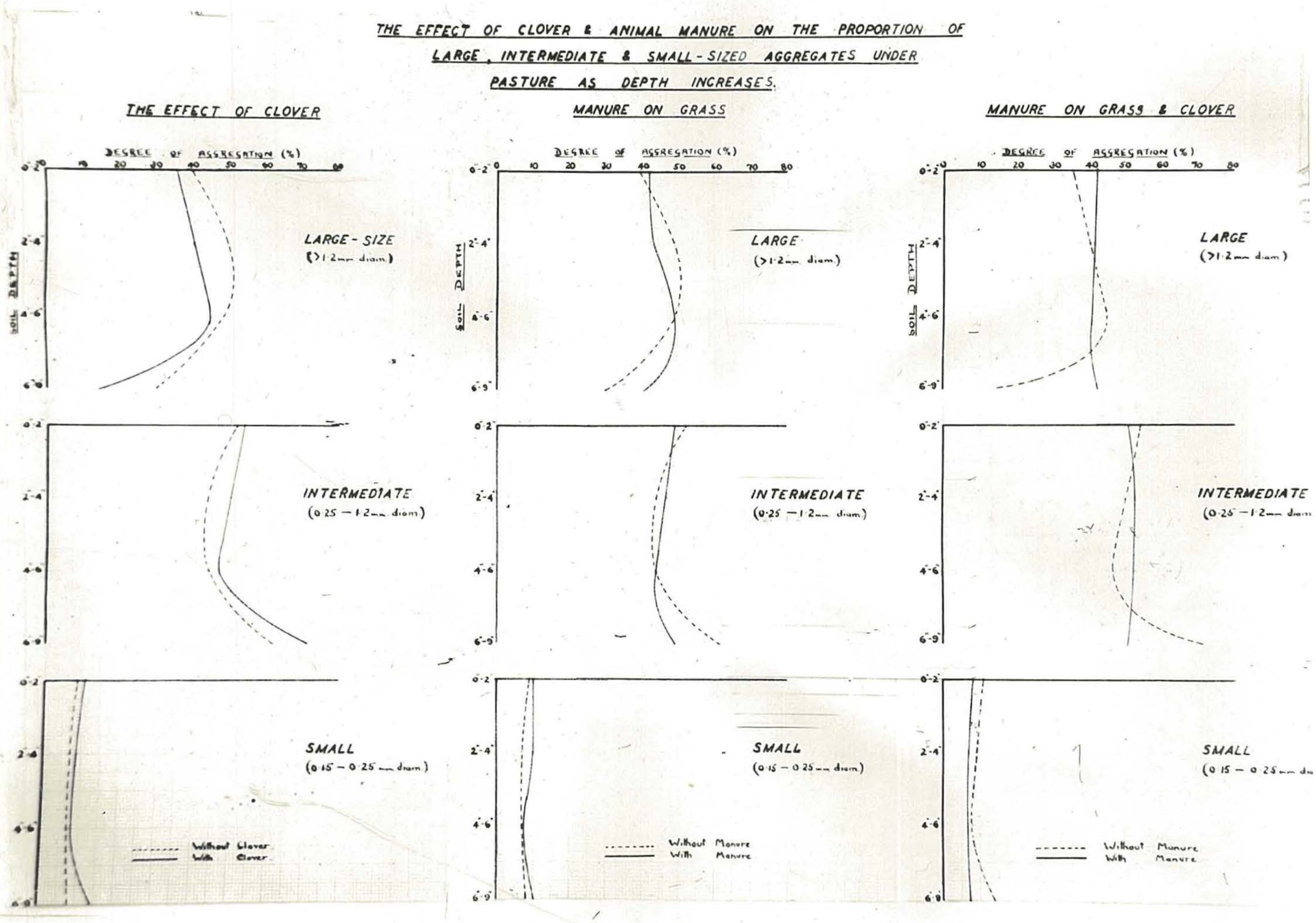
Grass + Clover with added Manure

At the following depths: 0"-2"; 2"-4"; 4"-6"; 6"-9".

As an aid to presentation, the term "Manure" often used throughout the paper, refers strictly to "Animal Manure". Also, the "influence of clover," wherever discussed, is always in combination with grass, as shown by diagram and photograph.

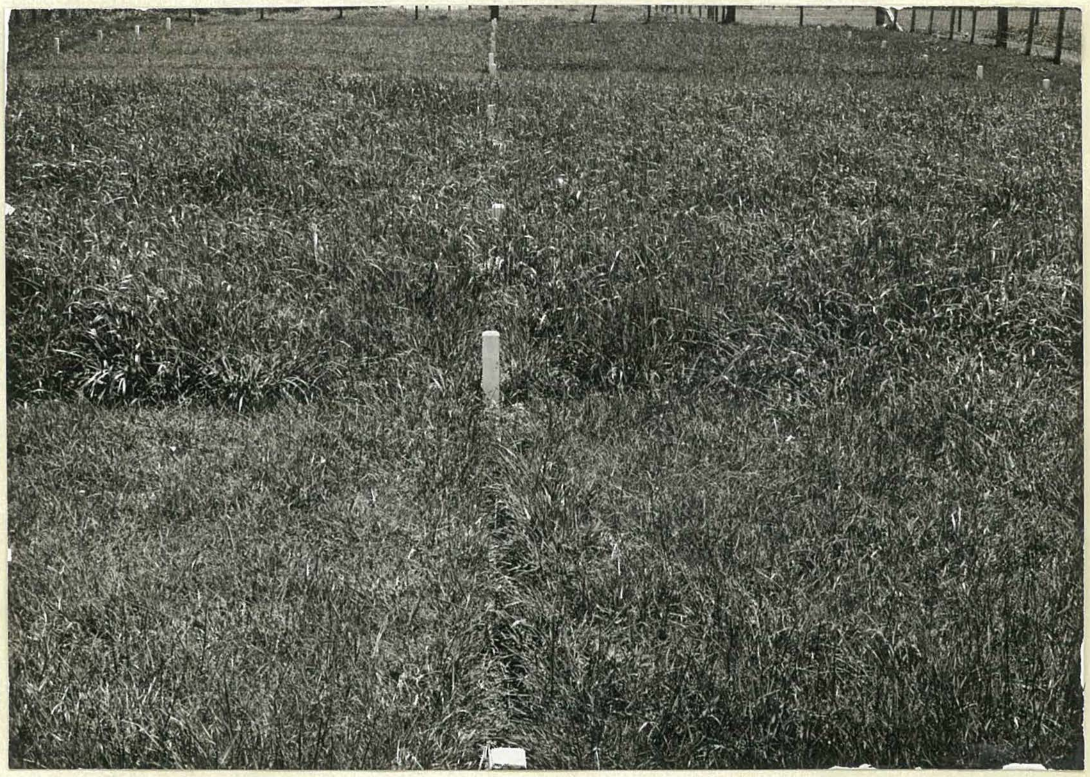
Aggregation Under Pasture: It appears that under permanent pasture a big proportion of the aggregates are large-sized particles. For instance, approx. 75% of the total aggregation occurring in the soil to the depth examined consisted of aggregates of diameter 0.42 m.m. Bouyoucos concluded from his investigations, although the type of cover was not mentioned, that the ultimate natural structure of most soils seems to be coarse, ranging in size from about 2.0 m.m. to 0.15 m.m.

clover on the degree of aggregation in the soil was not found appreciable. Only at the intermediate depth of 4"-6" was any improved state of aggregation recognised.



The graph serves to illustrate the influence of grass very effectively. Grass being more efficient than clover in building larger "crumbs" whereas the presence of the legume causes a predominance of slightly smaller particles.

The Effect of Animal Manure: The addition of manure alone to the grass sward did not result in any marked increase in the proportion of large-sized to total aggregates in the soil until the 6"-9" level was reached. However when in combination with clover the advantages were quite apparent particularly in the 0"-2" and 6"-9" - the only decline occurring in the 4"-6" layer and being of little significance.



The photographs possibly serve to illustrate the effect more clearly. Even although plot 1BB (grass only plus manure) presents the more desirable to a greater depth than any other treatment.

The smaller aggregates showed little variation, the manured plots tending to maintain a satisfactory level right throughout the soil depths measured, whereas the unmanured plots rose sharply at the 6"-9" layer. In other words, the grass and clover plants had been effective in building "crumbs" up to the 1.2 m.m. size but no further.

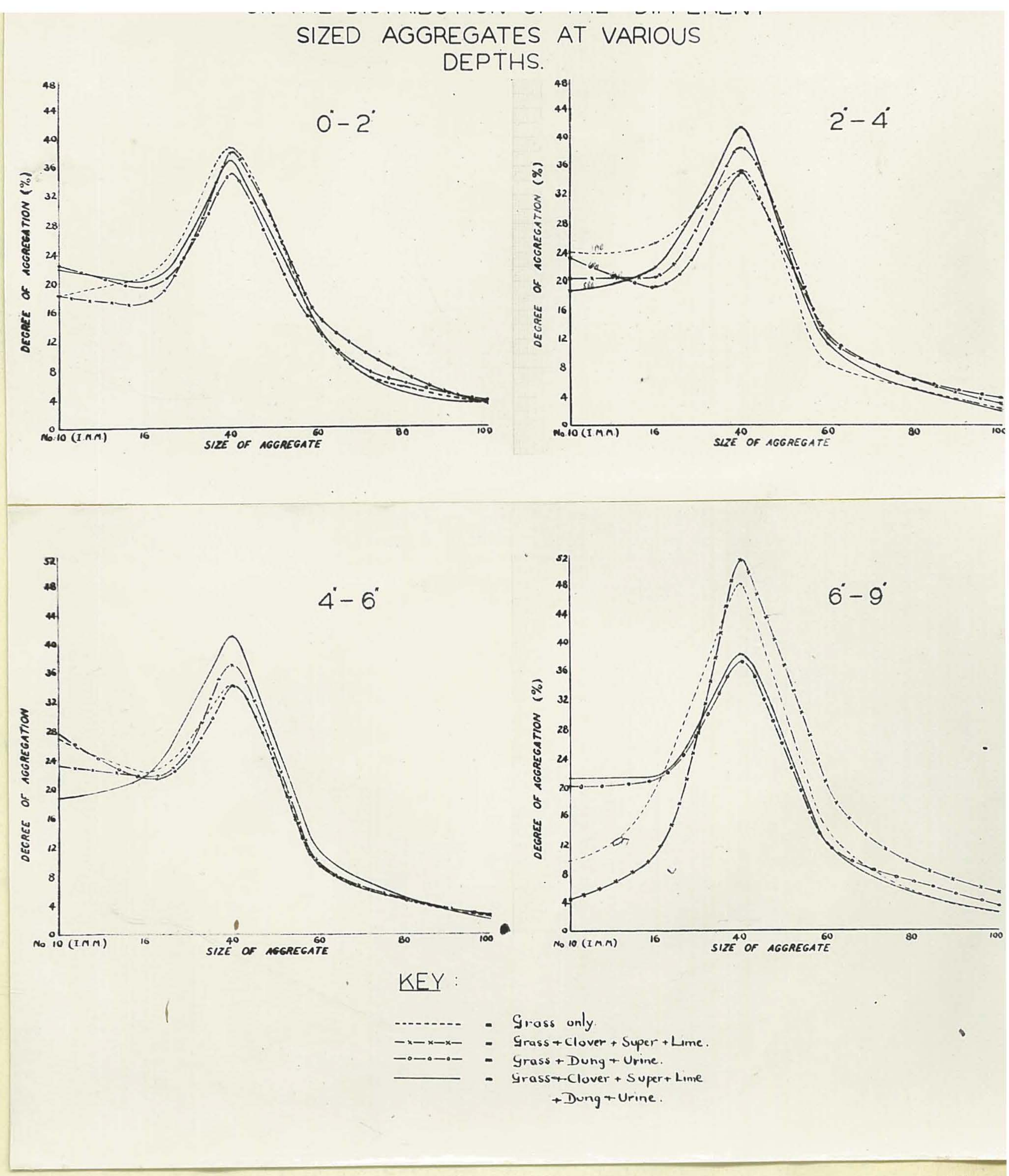
Graph

An examination of the influence of the various treatments on the percentage of total aggregates, both big and small, in the soil, emphasised once again the importance of animal manure and clover being present in combination with the grass sward. Whereas the manure without clover was effective in increasing total aggregation at the intermediate depths, the treatment incorporating the combination of both manure and clover grass alone was more effective in building a crumb structure than grass and clover combined, except for the small reverse at the 4"-6" level.

ILLUSTRATING THE IMPORTANCE OF GRASS+CLOVER PLUS MANURE ON TOTAL SOIL AGGREGATION.

The Total Degree of Aggregation (0"-9") of		Difference due to Clover plus Manure.
Grass & Clover plus Manure	= 73%	
Grass + Manure	= 69%	= 4%
Grass alone	= 67%	= 6%
Grass + Clover	= 62%	= 11%

Since Rust and Rowles ( ) considered that the organic matter influence on soil aggregation reached a limit when the level approached 2 to 2.5%, the differences in the degree of aggregation observed in the present investigation must therefore be attributed to factors other than organic matter i.e. microbial products, root exudates, manurial constituents, etc., since in all plots the level of organic matter was above 4%.



(a) Within Levels: The similarity in the shape of the curves obtained from graphing the influence of depth on aggregation, was most striking, as illustrated by the photograph.

Apart from the no-manure plots at the 6-9 level, the first two fractions i.e. the particles retained on the No. 10 and 16 I.M.M. sieves always fluctuated about the 20% level; the third fraction being significantly higher i.e. 35-40%; an equally rapid decline to the fourth fraction i.e. 12-15%; the curve levelling out to the fifth fraction at approx.

a few percent of the smallest-sized aggregates. At the 6"-9" level a similar variation existed but in the case of the no-manure plots the extremes were greater, i.e. the lack of large-sized particles was balanced by a greater percentage of intermediate-sized particles resulting in a similar total figure in common with the upper levels.

<u>Between Levels</u>: Apart from the treatment containing both manure and clover there was a general tendency for the proportion of large-sized aggregates (.1.2m.m.diam.) to rise gradually to a peak at the 4"-6" level and then fall away rather rapidly. In the manure plus clover plot (5BB) the quantity of large-sized particles was maintained at approximately the same level throughout the 9" soil profile, as illustrated in Photograph No. 3.

The variation in the percentage of intermediate-sized particles (0.25 to 1.2m.m. diam.) followed a completely opposite trend. Apart from the 5BB plot, which again displayed a constant but slightly higher level, the degree of aggregation declined gradually to the 4"-6" level and then rose sharply.

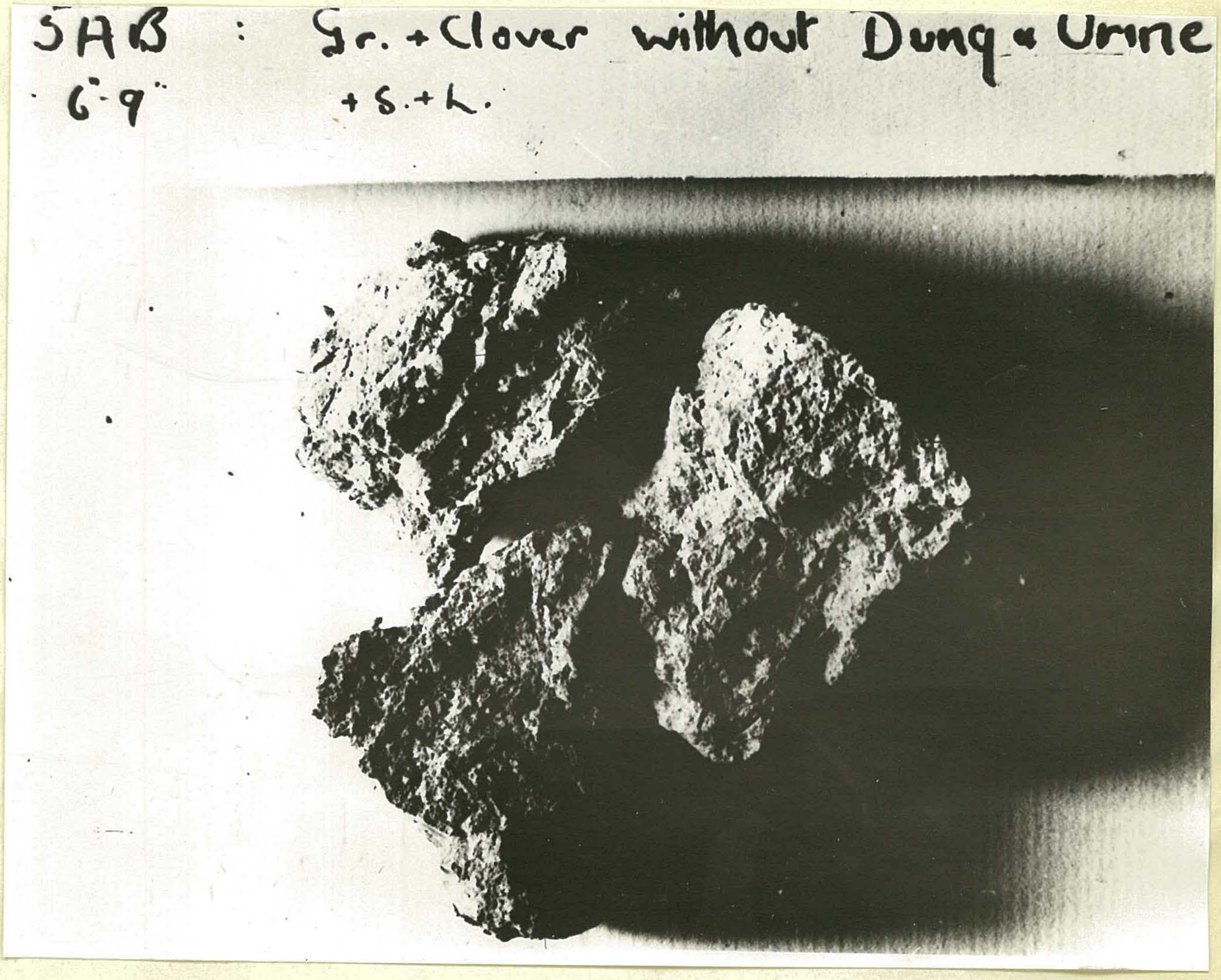
The proportion of small-sized aggregates (0.15 to 0.25 m.m. diam.) represented less than 10% of the total aggregation occurring under the various treatments and showed little variation.

When the total degree of aggregation of the soil i.e. all the aggregates from 0.15 m.m. to 4 m.m. diam, of each treatment was examined, there was a common tendency for aggregation to increase to a maximum at the 4"-6" level followed by a gradual decline to the 6"-9" level.

In view of the present work that is being investigated at "Grasslands" on the influence of earthworms on soil structure, it is possible that the larger aggregates, 1.2 m.m. diam., which show a maximum figure at the 2"-6" depth, may be due, in some degree, to the greater intensity of earthworm activity occurring within these soil levels.

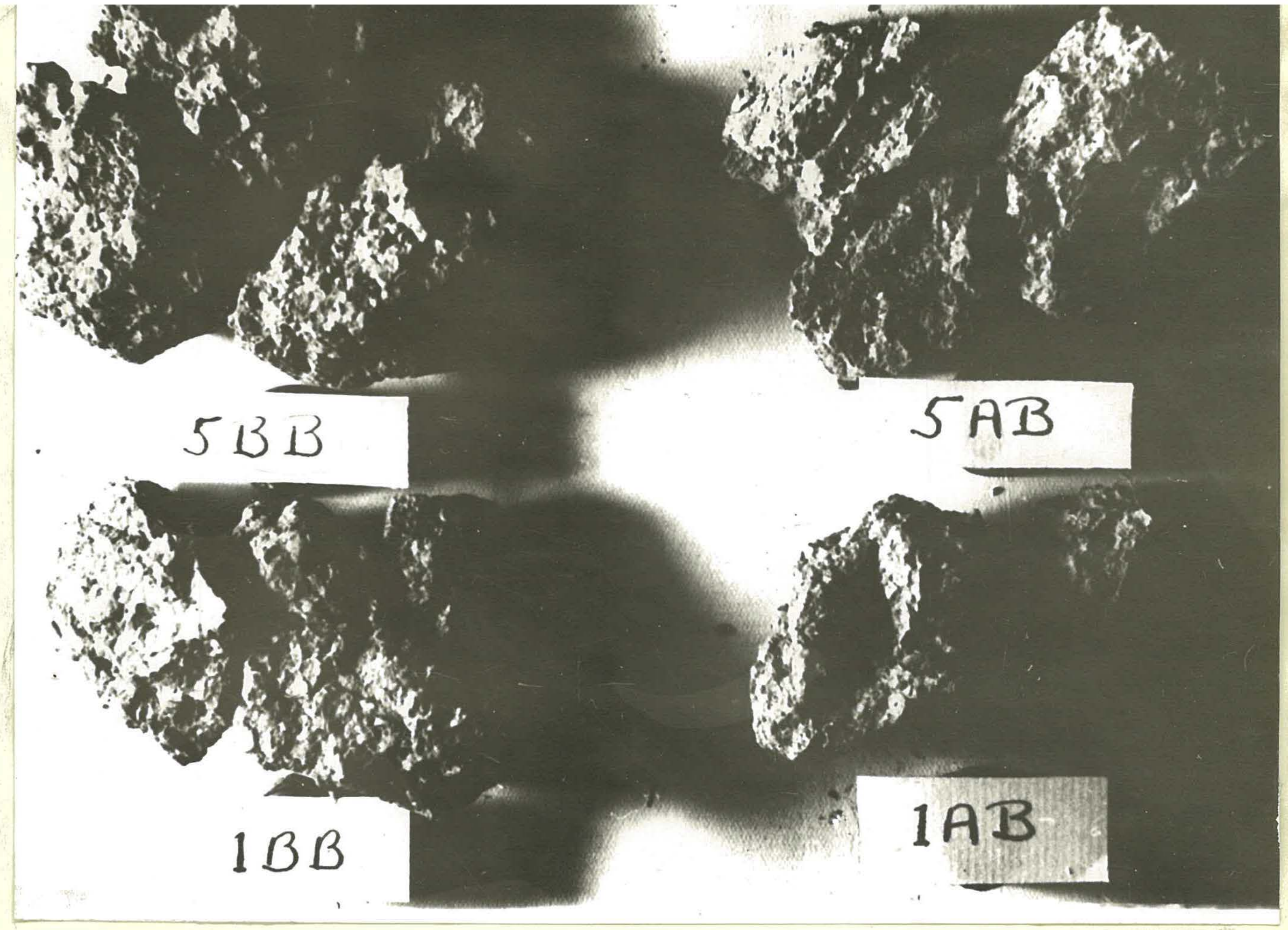
<u>Visual Differences in Aggregation.</u>

Because of the visual differences displayed by the representative lumps of soil being so obvious, particularly at the 6"-9" level, an



(a) <u>Description of Photograph 5AB</u> : (Grass + Clover No Manure) This sample displays a rather sheet-like appearance, particularly in the top left lump, due to the sharp edges, which are more apparent than in 5BB if examined closely. Also there is the appearance of a greater number of smaller particles or aggregates. This point is more clearly evidenced if the photographs are studied together.

(b) Description of 5BB : (Grass & Clover + Manure) : In this photograph the sharp edges seen in 5AB are absent, the aggregates being more distinctly cuboidal giving a granular shot-like appearance and consequently a rounded-edge affect. The aggregates also appear bigger in size, as borne out in the analysis.



(c) Description of All Plots: In the photograph above an attempt is made to present samples of all four plots. As a result, detail and definition has been sacrificed, nevertheless there is a tendency for sharp faces and edges to be more defined in all but the 5BB sample, as already mentioned.

- -

On the Acid-Soluble & Adsorbed Phosphorus in the Soil.

Method of Measurement : There is a tendency among some interpreters to misunderstand the significance of chemical soil tests. Chemical solvents may distinguish between soil phosphates which have a high availability to plants and those which have a low availability, but they do not measure exactly the availability of the phosphoric acid in these minerals. The availability of the latter to plants depends upon the kind of plant, the soil, and the conditions under which the test is made, so that results secured with the same phosphates in different tests may differ considerably. As Fraps and Fudge ( ) state, the solubility of soil phosphates is only one of several factors which affect the capacity of the soil to supply phosphoric acid to plants.

Well-known workers in this field, Bray and Kurtz ( ) in 1945 claimed and even presented methods to distinguish between the so called available forms of Phosphorus, dividing it into the "adsorbed" and "acid-soluble" forms. However from recent unpublished data by Fife ( ) it appears that such a division is not possible as the prescribed method for determining "adsorbed phosphorus" apparently just extracts the more difficult acid-soluble forms. In other words the so-called "adsorbed method" gives results relatively identical, but at a higher level, to the "acid-soluble method". The discovery of this fact was not made until mid-October, when the analysis concerned was discontinued. The chemical methods used in this investigation were as follows: the "acid-soluble phosphorus" fraction was determined by a modification of the Egner method, where a lactate buffer at pH 4.8 is used, by incorporating a section of the Bray and Kurtz method for the colour development.

: the "adsorbed phosphorus" fraction was determined by the Bray and Kurtz method, as described with the above in the Appendix.

gave an accurate representative sample.

The accuracy of the sampling technique was examined in the following manner.

Double samplings were made of two different treatments in both replicated plots, that is a total of 8 samples of 20 plugs each, and were found to give identical results. An additional check was also made as to the accuracy of the so-called repre entative sample. Two plots were divided into 5 sections each and 4 plugs taken at random - by tossing coins - from each section. The results showed that the mean of the sections gave the same result as that from 20 plugs over the whole plot, indicating that the technique to be employed was quite satisfactory.

The reason that a sample of 2" depth was chosen is due to the fact that the movement of phosphorus in the soil is considered very slow. Doak ( ) from his Marton trials concluded that for penetration of phosphoric acid to be obtained it was necessary to make heavy phosphatic applications at frequent intervals. Midgley ( ) however regarded only the surface inch of soil as the zone influenced to any degree, as also did Beater ( ) who stated that ~~an~~ movement of Phosphorus after application could not be traced appreciably below the first inch from the surface even in lighter soils, except occasional penetrations due to fissures. Consequently the zone of greatest accumulation and therefore greatest soluble fraction due to manure were recorded in all treatments, particularly the "grass plus clover" plots. For example, the "grass alone" plots were improved to the extent of 50-100% acid-soluble phosphorus content while the "grass and clover" plots showed increases of up to 600%. Even on the plots where super applications were a part of the treatment, the dung and urine doubled and in some cases trebled the amount of this phosphate fraction in the soil, which is considered to be available to plants.

On the adsorbed phosphorus: Although as previously stated, this determination was discontinued after approximately 7 months, the figures to that date indicated a similar response as that mentioned above but at a higher phosphorus level.

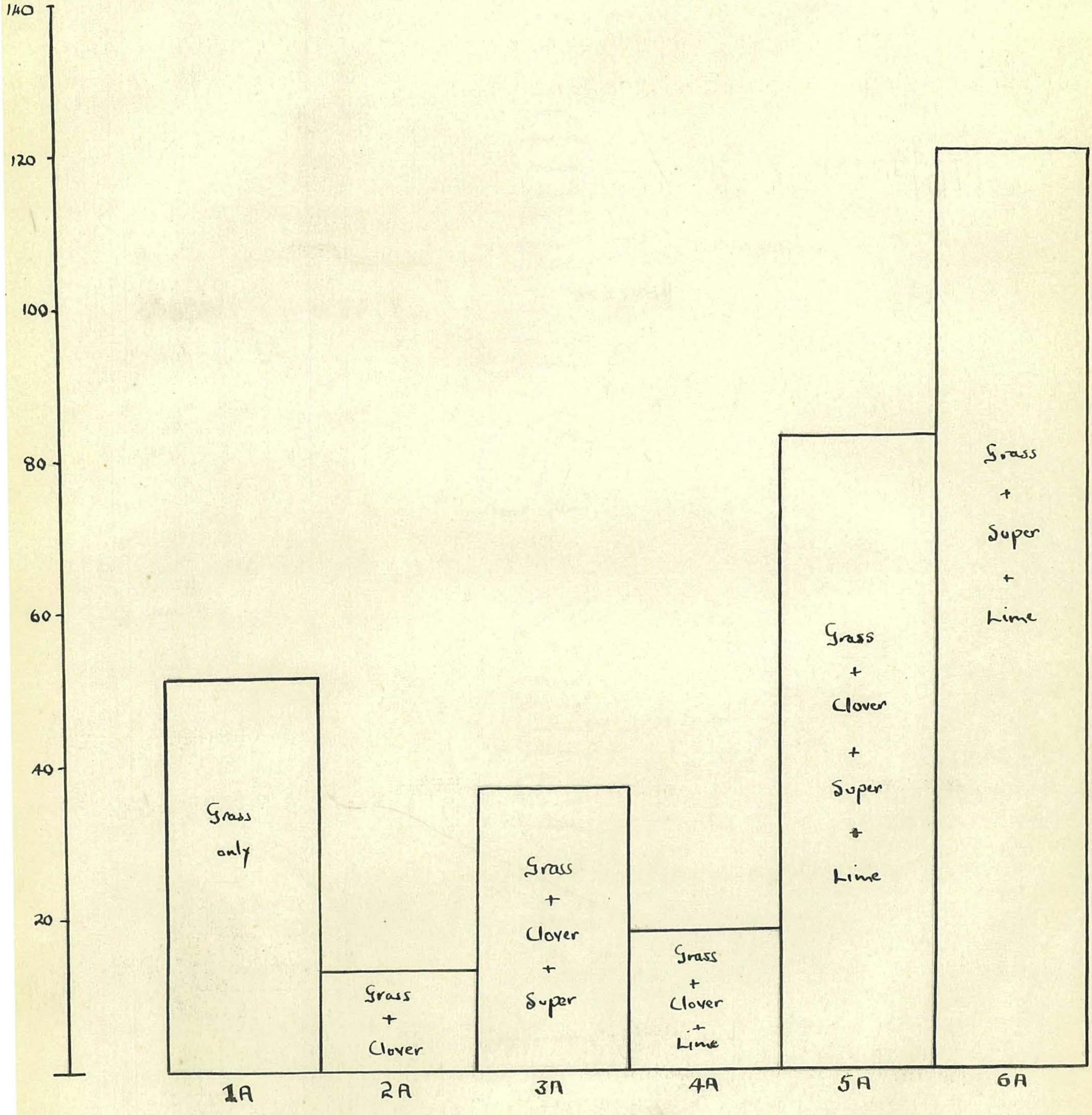
TABLE.

ILLUSTRATING THE INFLUENCE OF ANIMAL MANURE ON THE ACID-SOLUBLE PHOSPHORUS LEVEL IN THE SOIL. (3mths after Super application in each case).

Without Manure.	23/6/48.		8/10/48.		12/1/48.	
Grass :	51	lb. P_2O_5/ac.	46	lb. P_2O_5/ac.	41	lb. P_2O_5/ac.
Grass & Clover :	13	"	12	"	10	"
Grass & Clover & Super:	37	"	29		31	
Grass & Clover & Super & Lime. :	83	"	74		72	
Grass & Clover & Lime :	18		18		11	
Grass & Super & Lime :	120	"	113		103	
With Manure.						
Grass :	106	"	104		79	
Grass & Clover :	83	"	77		64	
Grass & Clover & Super:	119		122		121	
Grass & Clover & Super & Lime.	137	"	128		134	
Grass & Clover & Lime :	80		79		65	
Grass & Super & Lime :	173	"	165		164	

The "Adsorbed Phosphorus" figures followed much the same trend but at a higher level.

(the application of Lime & Superphosphate being equal for all plots concerned)



<u>Explanation</u> : 1A = can be regarded as a control - the phosphate level affected owing to the poor growth & therefore low demand.

2A = there is a noticeable reduction owing to the demands of the more productive pasture.

3A = the increase being due to the directi addition of Superphosphate.

4A = there is a slight increase over 2A - indicating a possibl effect by lime.

5A = there is a direct increase through the addition of Superphosphate and a further lift due to the lime influence.

6A = the biggest arise due to direct phosphatic application as above and also the fact that very little is withdrawn owing to low pasture demands.

significance to use the phosphorus, consequently the level changed only slightly.

It is interesting to note that the grass alone plot treated with Super responded in similar manner to the grass and clover plus Super treatment i.e. a decrease in the acid-soluble phosphorus level occurred after the phosphate application suggesting that whereas the grass and clover possibly used this phosphate for increased growth, the soil of the grass alone plot on which growth was negligible, apparently changed a similar amount into a more difficultly available and non acid-soluble form.

PHOSPHORUS RESIDUAL AND UTILISATION.

No-Manure Area :

In such high fertility soils, it is very difficult to attempt to follow the course of applied phosphate and measure its utilisation with the methods at present in use, the acid-soluble form periodically showing unaccountable fluctuations. There can be no doubt that this area was particularly well supplied with available or slowly available phosphorus at the commencement of the experiment, as proved by the high production on the no-manure "grass and clover" plots. However from figures of D.M. yields observed recently (July 1949) it appears that in these plots having no phosphate applied the reserve is beginning to denote signs of depletion.

After each application of superphosphate made on the 20th March (3cwt.) 9th July (3cwt.) and the 11th October (4cwt.), the results indicated that large quantities of P_2O_5 became stored or "tied-up" in unavailable form in the soil even although considerable increases in the amount of available phosphorus were recorded in the analyses. As the figures suggest, during the first intervening period of 3 mths. the pasture only drew on a very small amount of the added phosphate owing to its low productivity at that time. Of the remainder, the majority went into the so-called "unavailable" form and the rest into the store of "available" phosphorus. In the second intervening period, although the pasture removed approximately twice as much added phosphate, the soil nevertheless still rendered a large portion unavailable and moreover showed a decline, that is, an uptake from the "acid-soluble" supply. The explanation in this case appears to be associate form as in the first period. Later however, when the spring growth commenced, the plant naturally drew on the supply of available soil phosphorus and consequently a decline occurred in this fraction, as recorded.

In the third period when the pasture was most productive and soil activity was at a maximum, the plants were apparently able to use much more of the applied phosphate and in the case of the "grass and clover" plots didn't affect the available supply in the soil to any great extent at all. In the "grass alone" plot receiving superphosphate and consisting of those species which commence growth later in the season, very little of the applied phosphate was used, it being rendered unavailable. However when the plants did become active, they immediately drew on the store of available soil phosphorus, as discussed in the preceeding paragraph.

It appears, therefore, that when soluble phosphate is applied to a soil, as in this experiment, the plants make immediate use of a certain amount, possibly determined by some physiological phenomenon associated with the activity of the plant, or perhaps due to a soil temperature phenomenon causing variation, as observed by Robinson ( ), a further amount increases the store of available phosphorus and the remainder, usually the largest amount, is converted to a so-called unavailable or "residual" form.

If this possibility is actually the case, then the response from superphosphate on these plots is comparatively small and insignificant i.e. the difference between the yield of the "grass + clover" control plot and the "grass + clover + superphosphate" plot - as indicated by graphs 2A and 3A respectively. An illustration of this variation in phosphorus utilisation is presented in Table on the following page.

These conclusions were also considered possible from an investigation of the graphs of both soil phosphorus and herbage yields of the plots. When one inspects these graphs closely it can be seen that those of the No-manure + Superphosphate series agree quite satisfactorily with the D.M. / ac. curves i.e. there is a pasture response from the application of superphosphate which is also recorded in the soil analyses. However,

Period : 12/3 to 23/6/48.	Added in Super	Taken out by Herbage	"Availability" according to Pasture.	Effect on Acid-soil Phosphorus.	"Residual"	"Availability" according to plant & Soil.
Grass + Clover : + Super	67 lbs.	11.4	17%	+9(28to37)	46.6	30%
Grass + Clover : +Super + Lime	67	14.7	22%	+ 26(57to83)	26.3	61%
Grass + Super : + Lime	67	2.4	4%	+ 29(91to120)	35.6	47%
Period : 23/6 - 8/10/48.						
Grass + Clover : + Super	67	28.3	42%	-8(37to29)	46.7	30%
Grass + Clover : + Super + Lime	67	32.0	48%	-9(83to74)	44.0	34%
Grass + Super : + Lime	67	5.3	8%	-7(120to113)	68.7	0
Period : 8/10 - 12/1/49.						
Grass + Clover : + Super	90	63.6	71%	+2(29to31)	24.4	73%
Grass + Clover : + Super + Lime	90	68.8	76%	-2(74to72)	23.2	74%
Grass + Super : + Lime	90	12.4	19%	-10(113to103)	87.6	3%

Although an attempt is made to explain the above variations, it is obviously extremely difficult endeavouring to understand the phosphate relationship between Fertiliser, Plant and Soil. Nevertheless the quantity held in this "Residual" form is shown to warrant considerable attention, as the scientists of today are doing.

the reason being that the investigation was particularly concerned with tracing the added phosphate in the superphosphate treated plots. Consequently from a close study of the graphs it is possible that the curves of the no-superphosphate plots could be entirely different. In other words they could follow exactly the same trend as those of the superphosphate plots.

Another possible explanation is that the requirements of the pasture in the non-phosphated plots were met from a supply that was unrecordable chemically, for instance the organic phosphorus fraction of the soil. Whatever the correct explanation might be, the actual results obtained neither prove nor disprove the suggestions put forth.

A more intensive study was made of the October application of Superphosphate which is worthy of mention. Here the soil was analysed 3 days before 1 week after and 1 month after application, followed by monthly sampling till January. On attempting to analyse the data obtained, it became most evident that with such a method of measurement it was extremely difficult to equate the various available phosphorus fractions of soil and pasture. For example, after the October application of Super had raised the "availabl phosphorus level to its maximum, the decline from that point to a level 2 months later did not by any means coincide with the amount taken out in the herbage over that period, indicating, since the latter figure was the bigger, that phosphorus must have become available from some other unrecordable source as also shown by the "no-super" plots, presumably from the "residual phosphate" store. Whether it came from the adsorbed phosphorus or the organic phosphorus supply or whether the phosphorus was passed directly to the plant without affecting the measurable quantity or whatever may be the correct explanation must remain, for the present, unsolved.

Photo.

	(4 cwt. Super) on 8/10/48.		8/11/48.		12/1/49.
In Soil :	29 lbs.	25 →	54 lbs.	23 →	31 lbs.
In Herbage : (approx.)	x	12 lbs. →	x_1	52 lbs. →	x_2

[In other words because only 23 lbs P_2O_5 were recorded as being taken from the acid-soluble phosphorus fraction of the soil to supply the 52 lbs actually taken up between 8/11/48 and 12/1/49, the "residual" form must have supplied the difference of 29 lbs. i.e. this method does not measure all the "available phosphorus" in the soil.]

Manured Area : The above discussion has been intentionally concentrated on the No-manure series because of the clouding influence of the dung and urine. On the manured area any attempt to equate the various phosphorus fractions is virtually impossible owing to the tremendous unknown factors, dung and urine. An analysis of a random sample of sheep dung was actually made and found to contain almost unrecordably high amounts of acid-soluble phosphorus. Just how available this form is to the plant after being added to the soil can only be deduced from the fact that in the "manured" series the dry matter production from the unfertilised plots was equally as high as the production from plots receiving superphosphate and lime in addition. The level of available phosphorus maintained by the dung and urine applications in such soils is apparently well in excess of that required for maximum pasture production.

Because of the natural high fertility of the area concerned, it was felt that the affects due to the addition of superphosphate and manure were not as marked as would normally be the case.

The Influence of Lime : On the unmanured area the influence of lime at 10 cwt. / acre / annum, on soil phosphorus availability was to cause a slight increase in the "acid-soluble" fraction, as also intimated by the increased herbage yield and associated phosphorus uptake. Although this improvement was only slight it was nevertheless consistent right throughout the investigation. In the case of the adsorbed phosphorus fraction however, there was no response from the addition of lime. Considering the inaccuracy of the latter method only lesser attention can be paid to these results.

On the manured area the influence of lime, due to the presence of an interfering "fertility gradient," gave abnormal results.

Soil reaction was also measured in the various plots which readily separated the limed from the unlimed treatments. The reaction of the limed plots in the unmanured section ranged narrowly about pH 6.7 and the unlimed about pH 6.0. On the manured plots the effect of lime on soil pH tended to be masked by the influence of the animal excreta but nevertheless showed a difference ranging from approximately pH 6.3 in the unlimed plots to pH 6.9 in the limed plots.

Influence of Superphosphate: The addition of superphosphate caused a significant increase in both acid-soluble and adsorbed phosphorus in the soil, rising and falling with each application. Results indicated that the maximum level of acid-soluble phosphorus was not reached until about 3-4 wk after the application - in this case at the rate of 4 cwt. Super / acre - decreasing slowly to the previous level in approximately 3 months.

When lime was added in conjunction with the phosphatic fertiliser the effect was even greater. Both phosphorus levels were substantially raised above the amounts in the other plots but still displayed the same variation with each application. It appeared that the lime had caused a marked increase in the percentage of available phosphorus, in some cases nearly doubling the quantity found in the unlimed by phosphate-treated plot.

The influence of superphosphate on the soil pH was to cause a slow but steady increase in acidity. Even when lime was added in conjunction with the fertiliser, the pH level still remained below that of the limed plot although the amount of calcium carbonate added was identical in each case.

ON THE POTASH IN THE SOIL.

Method of Measurement :

The method used was the modification by Dixon and Metson of Spurway's quick test method ( ).

Effect of Animal Manure :

Although the soil of all plots showed a "moderate" to "very high" level of potash, the differences obtained between the manured and un-manured treatments were most striking, the amount being doubled and sometimes trebled by the manurial application.

Evidence of the tremendous supply of ultimately available K that must be stored in some soils can even be discerned from this minor section of the investigation e.g. after approximately 9 months of vigorous pasture growth, the level of potash in the 0"-2" of soil still remained in the "moderate" to "high" category. Although the results nevertheless tend to suggest signs of depletion, any statement relating to this possibility cannot be made owing to the very approximate method of measurement adopted.

Effect of Clover :

In using this method, such slight differences as might exist in the soil between clover and non-clover treatments could not be ascertained. However there appeared to be a slight trend, where no manure was being added, for the "clover" plots to be at a slightly lower exchangeable K level than the "grass" plots. This possibly suggested, that owing to the greater growth, such areas are kept at a lower level whereas the demand on soil potash by the low-producing "grass" areas is of little account. Nevertheless such interpretation must, under the circumstances, be accepted with reserve.

TABLE:

THE INFLUENCE OF ANIMAL MANURE AND CLOVER ON THE POTASH IN THE SOIL (0"-2") (expressed as p.p.m. K_2O)

	No Manure.	Manure.	No Manure.	Manure.
Grass alone :	48- p.p.m.	72 p.p.m.	32+ p.p.m.	48+ p.p.m.
Grass + Super & Lime :	32+ "	72- "	32 "	48+ "
Grass + Clover :	32 "	96- "	32 "	72+ "
" " + Super :	32 "	72+ "	16+ "	72 "
" " + Lime :	32 "	72- "	32 "	72 "
" "+Super&lime:	16+ "	72 "	16 "	48+ "

8 p.p.m.	=	Low Potash Content.
16 "	=	Moderate Potash Content
24 "	=	Moderately High Potash Content
32 "	=	High
48 & above	=	V. High

In attempting to measure intermediate differences the + & - signs were used e.g. 32 + p.p.m. & 48 - p.p.m. would represent a similar intermediate value.

The Total Nitrogen method used was that given by A.L. Prince ( )

Effect of Manure :

(a) Ammonia Nitrogen : Once again the manurial applications caused a substantial increase in the ammonia nitrogen level in the soil, particularly in the absence of clover.

(b) Nitrate Nitrogen : The response of the nitrate nitrogen level in the soil to the addition of manure was largely determined by the presence or absence of clover. When the latter was absent the response was negligible but when present a remarkable improvement occurred raising the nitrate level multifold.

Effect of Clover :

(a) Ammonia Nitrogen : Although the presence of clover in both manured and unmanured plots brought about an improvement in the ammonia nitrogen level of the soil, the extent of this benefit appeared to be linked with a seasonal influence.

(b) Nitrate Nitrogen : The nitrate response to clover was dependent on the presence of dung and urine. Without the animal residues the difference between clover and non-clover plots was insignificant but when such manurial additions were made the increase due to clover was clearly defined

TABLE:

THE INFLUENCE OF ANIMAL MANURE & CLOVER ON THE AMMONIA AND NITRATE NITROGEN IN THE SOIL. (expressed as p.p.m. of Soil)

Treatment	Ammonia Nitrogen			Nitrate Nitrogen.		
	19/8/48.	22/10/48.	22/12/48. :	19/8/48.	22/10/48.	22/12/48.
Grass only	4	29	20	7	9	8
Grass + Clover	11	32	30	3	10	8
Grass + Manure	18	38	28	2	11	4
Grass + Clover + Manure	26	38	40	42	32	79

First Analysis made 14 days after Urine application.
Second " " 7 " " " "
Third " " 7 " " " "

Seasonal Trend :

Although determinations only covered a period of 4 months, there were consistent indications of a seasonal variation on the level of available nitrogen in the soil.

Ammonia Nitrogen : As shown in the graphs, there was a definite delay by some plots in reaching a maximum due to the presence of clover. The "grass abne" plots irrespective of manurial application dropped quite sharply in their "ammonia" content after the October sampling whereas the "grass plus clover" plots exhibited in one case a slightly later peak and in the other mid-summer maximum. Such a phenomenon indicates the mounting influence of soil temperature and soil moisture conditions as the season advances and although it is probably linked with pasture activity, just how much may be due to the influence of increased growth giving more suitable cover and therefore soil conditions more favourable to micro-biological processes concerned with available nitrogen in the soil, is of definite interest. In other words the influence of clover on the amount of ammonia nitrogen present in the soil is probably both direct and indirect Direct, through the effect of associated symbiotic bacteria leading to greater pasture production, and indirectly, through the more favourable environmental conditions existing in the soil over a longer period due to the increased pasture growth.

Nitrate Nitrogen :

In three of the treatments the seasonal trend followed that of the "ammonia" fraction. However in the fourth treatment, the plot of highest productivity, there was a decisive accumulation in "nitrate" content in the final sampling which, as expressed by other workers, is associated with the temperature and moisture conditions prevailing over this dry summer period.

nitrogen status in the soil than did manure added toa an entirely grass sward, the combination of both factors resulted in a substantially higher nitrogen level -

e.g. There was a Progressive Total Soil Nitrogen Percentage as follows:-

Grass ⟶ Grass + Manure ⟶ Grass + Clover ⟶ Grass + Clover + Manure.

Although this available fraction - ammonia plus nitrate - represents such a small percentage of the total soil nitrogen it is well to remember that it is available and therefore of vital importance to pasture production.

TABLE:

THE EFFECT OF ANIMAL MANURE AND CLOVER ON THE TOTAL NITROGEN AND THE RATIO OF AVAILABLE TO TOTAL N IN THE SOIL.

		Total N%	Available / Total.
Grass	:	0.233	1.2%
Grass + Clover	:	0.274	1.4%
Grass + Manure	:	0.253	1.3%
Grass + Clover + Manure	:	0.332	3.6%

The method used for the determination of organic matter was that devised by Schollenberger ( ).

Effect of Manure:

In both the grass and grass plus clover plots increases in the level of organic matter of 17% and 28% respectively can be attributed to manurial applications. Similarly, as shown in the final analyses, this improvement was maintained and in the soley grass plots of lower productivity even increased slightly.

Effect of Clover:

The effect of clover on soil organic matter without manure, only showed an increase in the final sampling. When in combination with manure however, the improvement of approximately 10% was readily recognised from both analyses.

The percentage increase in the level of soil organic matter of the various treatments over the intervening ten months between samplings, is of particular interest.

In the "no-return" of dung and urine series

Grass = 13%

Grass + Clover = 23%

In the "proportional return" series

Grass = 19%

Grass + Clover = 19%

In other words, the dung and urine caused a greater increase in the organic matter content of the low fertility "all grass" plots, while in the higher fertility unmanured, clover - dominant — because of the treatment — grass and clover plots, the organic matter supplied through the presence of the clover was sufficient to exceed the percentage increase in the manured, grass-dominant — because of the treatment — grass and clover plots due to the addition of animal manure. However, when the actual amounts of soil organic matter are considered, the superiority of these two combined factors, in the building up of this level, is readily recognised.

Grass	(No Manure)	=	~~4.44%~~ 4.36	13%	~~5.00%~~ 4.8
Grass + Clover	(" ")	=	4.44%	23%	5.46%
Grass	(With~~out~~ Manure)	=	5.13%	19%	6.12%
Grass + Clover	(" ")	=	5.68%	19%	6.74%

The Carbon - Nitrogen Ratio

The C/N ratio existing in the soils of the various treatments selected, showed no significant variation from that found by Fife ( ) in his study of some soils under pasture at Massey College. As evidenced right throughout the present investigation, the high fertility grass and clover plus manure treatment again displayed maximum efficiency by achieving a much higher level of soil nitrogen at the same C/N ratio.

TABLE:

THE INFLUENCE ON THE C/N RATIO.

		N%	C%	C/N
Grass	:	0.233	2.67	11:1
Grass + Clover	:	0.274	3.07	11:1
Grass + Manure	:	0.253	3.20	12:1
Grass + Clover + Manure	:	0.332	3.80	11:1

The Effect on the Water-holding Capacity:

As a requirement for the ammonia and nitrate nitrogen analyses it was necessary to calculate the water-holding capacity of the soil, by the oven-drying difference method. Although only a rough estimation, variation was observed in the ability of the treatments to hold water which was apparent at every determination.

The addition of clover to the sward resulted in a high increase in the water-holding capacity of the soil which was most apparent in the absence of manure. With the addition of dung and urine this soil characteristic immediately showed an improvement and maintained this superiority right throughout the investigation.

THE INFLUENCE OF ANIMAL MANURES AND CLOVER ON THE WATER-HOLDING CAPACITY OF THE SOIL.

(expressed as % wt. of Soil)

		14/5/48	19/8/48	22/10/48	22/12/48
Grass	:	23.60%	25.58%	26.18%	22.12%
Grass + Clover	:	24.18	26.44	27.38	22.62
No Dung & Urine	:	23.89%	26.01%	26.78%	22.37%
Grass + Manure	:	24.98	26.72	28.80	24.44
Grass + Clover	:	26.02	27.54	28.38	23.08
With Dung & Urine	:	25.50%	27.13%	28.59%	23.76%

each sampling. The earth and turf was then crumbled and separated completely and the worms collected. The latter were then washed gently in water, dried on blotting-paper, counted and weighed. After each sampling, except the first, the worms from the plots showing the biggest differences were identified.

The method used for sampling - the spade - proved to be the most suitable. Methods used elsewhere such as:-

The Permanganate, the Formalin, and the Electric Shock Method were found inaccurate, only causing those worms within the top ½" of soil to emerge. When the experimental sod was examined, those below this depth affected by the solution appeared to be too weak and inactive to reach the surface.

When killing for identification, a 25% solution of ethyl alcohol was added slowly to the beaker of water containing the worms. If added too quickly, rapid killing results, causing anterior segments to be withdrawn within the prostomium making identification difficult and inaccurate.

The accuracy of the technique was limited however, owing to the size of the experimental area and the consequent inability to take too many samples, which would have adversely affected the results of the major "grass production" project on which the above was super-imposed.

FACTORS AFFECTING NUMBERS AND WEIGHTS OF EARTHWORMS.

(a) Animal Manure:

In the first two examinations of the plots, there was very little difference in the earthworm populations between manured and unmanured treatments, except in the case of the "grass" plot where a definite increas due to manure was observed at the September sampling. However in the November and January samples a distinct response to the manure was evidenced in both "grass" and "grass plus clover" treatments.

The addition of dung and urine to the soil also resulted in a higher proportion of bigger worms as indicated by their average weight. This difference in size tended to be narrowed as the season advanced.

on the

EARTHWORM POPULATION UNDER GRASS & GRASS & CLOVER.

	Grass & Clover		No. of Worms/sq.ft.	Av.Wt./worm.	Wt./ac. (lbs)
19/5/48	No Dung & Urine	:	44	0.25 gms.	1031
	With " " "	:	41	.31	1236
8/9/48	No Dung & Urine	:	73	.28	1938
	With " " "	:	77	.32	2388
15/11/48	No Dung & Urine	:	45	.29	1266
	With " " "	:	60	.39	2253
25/1/49	No Dung & Urine	:	27	.32	835
	With " " "	:	38	.32	1152

TABLE:

	Grass alone		No. of Worms/sq.ft.	Av. Wt./worm.	Wt./ac/ (lbs)
19/5/48	No Dung & Urine	:	15	0.18 gms.	251
	With " " "	:	14	.19	249
8/9/48	No Dung & Urine	:	27	.23	633
	With " " "	:	58	.24	1382
15/11/48	No Dung & Urine	:	14	.20	289
	With " " "	:	29	.30	874
25/1/49	No Dung & Urine	:	7	.16	107
	With " " "	:	21	.18	350

(b) Clover:

Apparently the earthworm as well as the agrostologist realizes the importance of clover in a sward, as the figures obtained revealed a substantial increase in the population and size of worms present in the "grass & clover" as against the "grass only" plots.

"GRASS & CLOVER" ENVIRONMENT.

			No. of worms/sq/ft.	Av. Wt./worm	Wt./ac. (lbs)
19/5/48	Grass	:	15	0.18 gms.	251
	Grass & Clover	:	44	.25	1031
8/9/48	Grass	:	27	.23	633
	Grass & Clover	:	73	.28	1938
15/11/48	Grass	:	14	.20	289
	Grass & Clover	:	45	.29	1266
25/1/49	Grass	:	7	.16	107
	Grass & Clover	:	27	.32	835

Pasture production (Sears unpublished) also showed a similar and significant difference in the amount of dry matter produced by the "grass" and "grass plus clover" treatments. It would appear that the earthworm population possibly bears some relationship to the dry matter production of the sward. However, the picture is rather complicated by the added effects of temperature, rainfall and possibly their differing life cycles. For example, earthworm population showed a strong correlation to dry matter production from June to October, but after that period the relationship distinctly deteriorated; whereas pasture production soared tremendously, the worm population in some cases continued to fall.

A rather striking realization of the earthworm status of some soils is obtained when these "plot" figures are converted to a 'per acre' basis.

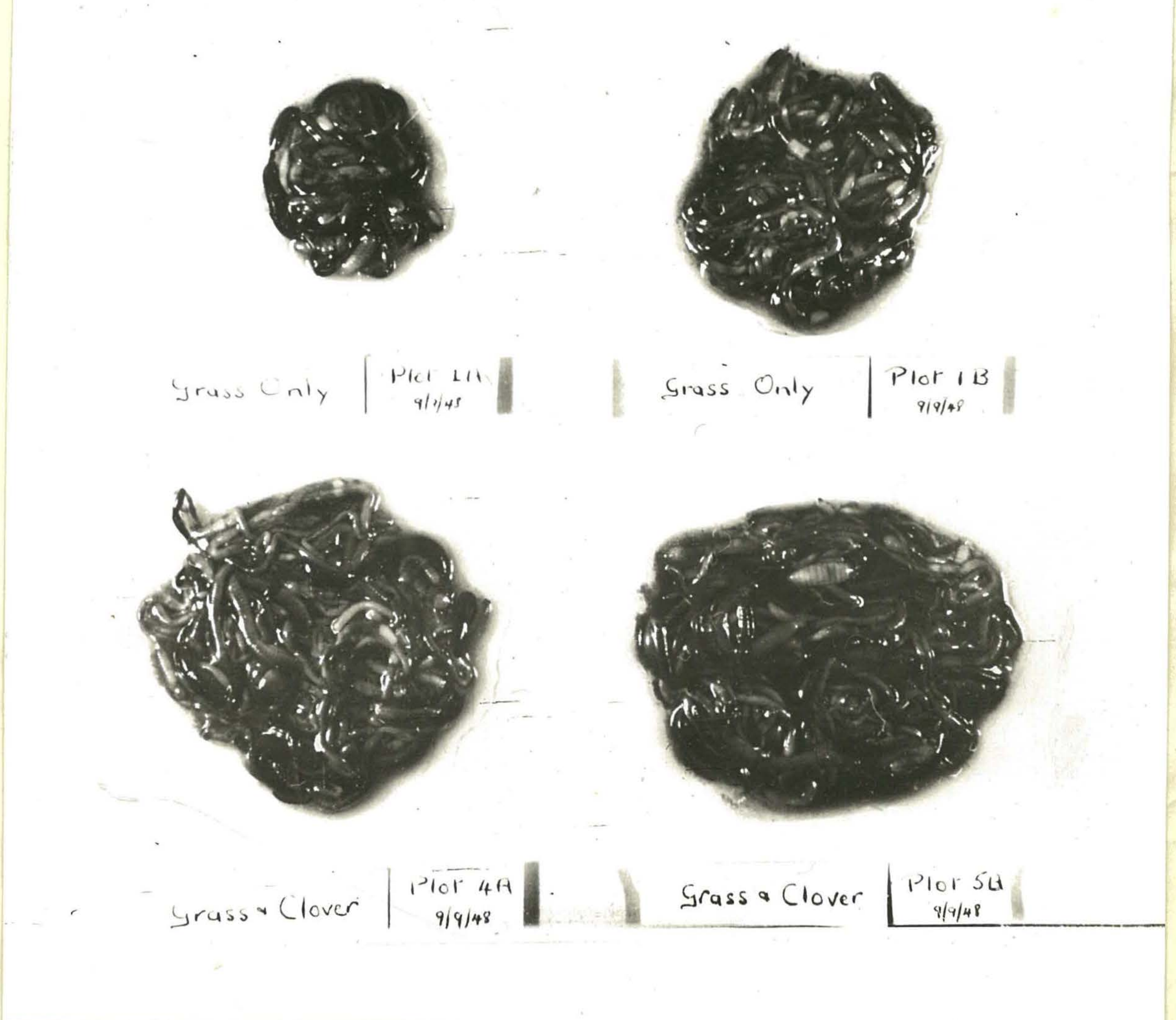
The population of worms varied from

½ million to 4 million / ac.

The weight of worms varied from approximately

1 cwt. to 22 cwt. / ac.

A relative indication of the earthworm populations of the treatments is illustrated in the following photograph.


Grass Only
Plot 1A
9/9/48
Grass Only
Plot 1B
9/9/48
Grass & Clover
Plot 4A
9/9/48
Grass & Clover
Plot 5B
9/9/48

Graph

naturally move away from the harder conditions - the "grass" plot - and thrive in their new habitat, where the food is more succulent above ground and of equal quantity in the soil and where temperature and moisture conditions are much more favourable; an example of habitational preference. However, if these creatures found themselves under "hard" conditions with no avenue of escape, the evidence available from literature indicates that the fertility status of the soil would be decidedly improved through their activities.

Seasonal Activity: In all treatments the worm populations reached a peak in the September sampling followed by a steady decline which tended to level off at the end of January.

Graph

to the final sampling in January. The worms of the remaining treatments continued to grow and although in the "dung and urine" series reached full size in November and then declined, those of the "grass and clover" treatment continued this gradual rise right up to the final sampling - as illustrated graphically below.

The reason for this possible abnormality is considered to be entangled with the environmental conditions existing over that period and influencing soil moisture and soil temperature levels. The suggested explanation is as follows; dry matter production of the "grass and clover" treatment increased tremendously from October to January and consequently insured sufficient growth to maintain a more suitable soil moisture and temperature condition for the worms. In comparison, the herbage growth of the remaining treatments was less and the plots consequently more open, therefore the worms probably felt the effects of the summer heat and lower moisture content much more quickly, particularly in the most open "grass only" plot, and quite possibly, as described by Evans ( ) exhibited a facultative diapause earlier.

It is felt that owing to the mild winter experienced in N.Z. as compared with U.K. the earthworm activity is not reduced to such a level as found at Rothamsted. When one considers that the coldest month last year recorded a 4" av. soil temp. of 46.3°F. it is reasonable to expect that the worms would be more active than those found in U.K. soils where the soil temperature falls below freezing point e.g. the 4" soil temperature at Rothamsted Jan. 1946 dropped to 31.9°F. Consequently it is considered that in the Manawatu and like climatic areas, the limitation to earthworm activity is due more to the heat and dryness of our summers rather than to the wet and cold of our winters.

An examination of the number of adult identified worms from the selected plots, tended to substantiate this environmental influence mentioned above, which wasn't evident from the figures on total worm population. That is, the number of worms identified from the manured plots suggested a more prolonged and slightly later period for the maximum level to be reached.

Graph

Graph

Although cast production was not measured in this experiment, the species identified here did not coincide completely with the casting species at Rothamsted. Considering the large amount of casting that was observed to take place at various times during the year, it is hardly likely that the few Allol longa identified were soley responsible. Considering also the fact that A. caliginosa, according to Dr. W. Benham, is so widespread throughout N.Z. it seems probable that this species - also recognized by Ashmore (   ) - may be one of the most important and valuable casting worm in this country.

(d) Factor Affecting Species Distribution.

Using Benham's identification key, the genera identified were Lumbricus and Allolobophora and within same the predominant species were L. rubellus and A. caliginosa (confirmed by W. Benham). No other Lumbrius species could be found at any stage of the experiment, but other species of A. were observed, viz., occasionally a few A. longa.

Just as Evans and Mc L. Guild(   ) found big differences in the dominant species on different fields at Rothamsted, similar variations in dominance were observed on the high and low fertility plots of the present investigation, as shown in the following table.

TABLE

THE EFFECT OF FERTILITY ON SPECIES DOMINANCE

of

ADULT WORMS.

			No. of Lumbricus Species 1 sq. ft.	No. of Allolobophoral species 1 sq. ft.
8/7/48	Grass	:	3	12
	Grass and Clover	:	25	14
	Grass	:	4	10
	Grass and Clover	:	16	13
	Grass	:	1	2
	Grass and Clover	:	7	3

[Although the number of immature Allolobophoral species at each sampling was a comparatively high figure, it did not appear to influence and clover" plots of high productivity Lumbricus species dominated the population. This difference was apparent at every sampling.

Due to this consistency, it appears that the Allolob. species are capable of withstanding the harder soil conditions which present, apparently, too difficult an environment for lumbricus species. This possibility enables a greater appreciation of the benefits attributed to the worm, A. caliginosa, by Ashmore ( ) Moreover it suggests the relative ability of the two species as builders of soil fertility.

That such variations may exist between the different species of earthworms as regards their usefulness in the soil, becomes an important factor when considering large scale practical use of these creatures as a means of improving the fertility of certain areas in this country.

(e) Effect on Soil Productivity:

Chemical.

To observe their effect on the available soil phosphorus, a random collection of casts was taken from a few selected plots on the same day as the normal plugging. Considering that the soil used for comparison is, in some areas, very high in fertility, the worms casts nevertheless reveal the following effect. The phosphorus determination was carried out using the modified method of Eqner's.

TABLE

THE INFLUENCE OF THE EARTHWORM ON PHOSPHORUS AVAILABILITY IN THE SOIL. (taken 8/10/48)

		Casts alone.	Plot Soil (+ Casts)
Grass	:	24.8	21.3 (expressed as mg. PO_4/100 g Soil).
Grass and Clover without Manure	:	27.2	22.7
Grass and Clover with Manure.	:	77.4	33.3

It is interesting to note that the increase in availability in the manured plot is substantially higher. In other words, where the organic matter - their food and nutrient supply - is much higher, the earthworm they occur in such numbers as found in this experiment, must be of significance to plant life with their supply of nutrients, especially nitrogen.

e.g. Considering each adult worm supplies 10 mg. N (14) when dead, then the following calculations using experimental figures is quite revealing.

Average number of mature worms at 8/9/48 in a
"Grass & Clover" plot
= 46

Average number of mature worms at 15/11/48 in same plot
= 25

∴ Dead worms = 21
= 914, 760 worms / acre.
= 9,147,600 mg. N/acre.
= 100 lbs. Sulphate of Ammonia (approx.)

When one realizes that the period concerned is only approximately two months, that the worms considered are only the mature ones and that the above figure is an average; then it is not difficult to imagine the annual benefit in nitrogen to some soils through the presence of the earthworm.

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tendencies were recognized throughout the investigation and will be presented in the order as already established.

<u>Structural</u>: It appears that under pasture conditions generally, from browntop-fescue swards (as in 1 AB) to ryegrass - white clover mixtures (as in 5 BB), there is a strong tendency towards the establishment of a satisfactory soil structure with maximum aggregation occurring about the 4" - 6" level. The pasture plants in themselves, their roots, their exudates and their associated rhizosphere bacteria, are undoubtedly the primary factors. However, in order to reach that excellence in desirability and stability of "crumb" structure under grassland conditions, the added influence of animal manure in the presence of clover is essential. It was largely through the cementing, aggregate-forming substances supplied by the dung and urine and augmented by the presence of clover, that such a depth of desirable structure, as exhibited by the "5 BB" treatment, was attained.

<u>Chemical</u>: <u>Phosphorus</u>: The very fact that one of the soil phosphorus determinations proved unreliable and had to be abandoned during the period of investigation, emphasizes the necessity for research into more accurate methods of measurement that will effectively separate and measure the various phosphorus fractions in the soil. Until this is accomplished one cannot expect the complex "phosphorus cycle" to be fully understood and explained.

The effect of animal manure on the "available phosphorus" status of the soil (0"-2") appeared to substantiate the significant increases recorded by the workers reviewed. The application of lime in itself tended to cause a very slight but rather insignificant improvement in the level of acid-soluble phosphorus in the soil, but when in combination with superphosphate, the phosphorus utilisation of the latter was materially increased over that when superphosphate was applied alone. At the same time, there was a delay of 3-4 weeks after the phosphate application before maximum availability was reached.

The mechanism involved in the fixation of phosphorus in soil under present experiment.

Potassium: Apparently the supply of available potash stored in the soil concerned, was extremely plentiful as evidenced by both soil and pasture analyses. Nevertheless the addition of animal manure caused the level of K_2O in the soil to double and often treble, indicating little likelihood of a deficiency ever occurring.

Ammonia & Nitrate Nitrogen: The maximum level of nitrogen present in soil under pasture conditions appears to be dependent on the presence of both clover and manure on and in the soil. When combined, these factors caused a notable increase in both the total and available nitrogen present in the soil.

Although the analyses only covered four months, a seasonal trend in the level of ammonia and nitrate nitrogen occurring in the soil, was indicated. The variations recorded suggested a possible correlation with seasonal plant activity. However with the approach of higher temperature and lower moisture conditions in the soil, the "available" nitrogen level commenced to decline in practically all treatments even although pasture production was rising to a maximum. In the exceptional treatment, the highest fertility plot, a nitrate accumulation occurred, as expressed by previous workers. Nevertheless, the results revealed the value of including a high-quality clover in the sward and the benefits derived from the judicious handling of the grazing animal.

Organic Matter: The results suggest that under grassland, any factor that will increase pasture growth will lead to a build-up of organic matter in the soil. In other words, it is the sod-forming pasture plants that are of primary importance, the effect of manure and clover, speaking of it here only as a source of nitrogen, being mainly of indirect value, in that pasture production as a result is increased allowing the plants, through their root and leaf residues, to raise the level of the soil organic matter higher. Nevertheless one should not forget, that it is the manure and/or the clover which enables that organic matter level to be further increased.

Earthworms: Although earthworms apparently follow fertility - a natural doubtedly influenced by such unknown factors as rate of reproduction, breeding season, etc., is presumably largely dependent upon soil temperature and soil moisture conditions. And since plant coverage is directly correlated with such soil conditions, the effects of animal manure and clover on pasture production must be considered of probable though indirect influence on worm activity.

The possibility that a species difference exists as regards their ability to withstand varying levels of fertility and environment, is of obvious importance to any large-scale practical use of the earthworm. From a study of the literature and current results, there is a strong indication that A. caliginosa is the important casting worm in this area and possibly this country, and able to withstand a more difficult environment than L. rubellus.

An appropriate conclusion is found in the fitting tribute paid to the earthworm in the profound statement made by Darwin ( ).

> "It may be doubted whether there are many other animals which have played so important a part in the history of the world as have these lowly-organised creatures."

may be summarised as follows.

Structural: (a) Animal manure caused a greater degree of aggregation in the soil (0".9") than clover. However for maximum aggregation to occur the addition of clover, as well as manure, to the sward was necessary. The greatest degree of aggregation occurred at the 4"-6" level.

(b) Of the individual aggregates : the percentage of large-sized particles usually increased with depth to approximately 50% of the total aggregation at the 4"-6" level and then declined; the intermediate-sized particles generally decreased in percentage with depth to approximately 40% of the total aggregation at the 4"-6" level and then increased; the small-sized particles showed little variation about the 10% mark.

(c) The variation in the size-distribution of aggregates with soil depth was the same at every depth measured, the maximum percentage being consistently of aggregates of size 0.42 m.m. to 1.2 m.m. diam.

(d) Because the influence of animal manure plus grass and clover on soil aggregation and on the shape of the individual crumb could be distinguished so readily with the naked eye at the 6"-9" level, an attempt was made to record the differences photographically.

Chemical: (a) Phosphorus: 1. The addition of animal manure to the soil resulted in a 100-600% increase in the level of acid-soluble phosphorus in the soil, the response being dependent upon the quantity added, therefore upon the productivity of the pasture which in turn was dependent upon the absence or presence of clover in the sward. When superphosphate was added the response due to manure was from 50-100% depending also on the absence or presence of clover.

ii. The utilisation of this soil phosphorus appears to be significantly controlled by the pasture plants themselves.

iii. The addition of lime in itself was of little benefit to the acid-soluble phosphorus level in the soil, but when applied in the presence of Superphosphate, it caused a marked improvement in the degree of utilisation of the phosphate contained in the fertiliser.

while the addition of animal manure decreased acidity.

(b) Potassium: The addition of animal manure to the soil increased the potash content, expressed as p.p.m. K_2O, by 100-400%, being dependent upon the quantity added and therefore indirectly on the presence or absence of clover.

(c) Ammonia & Nitrate Nitrogen: i. Animal manure was more effective in raising the "available" nitrogen content than clover. However for the maximum level to be obtained it was necessary for both manure and clover to be present in the soil and sward.

ii. Total nitrogen content showed a similar maximum when both manure and clover were present, but individually, clover was more effective, in this case, than manure in raising the soil nitrogen level.

iii. A seasonal influence on the amount of ammonia and nitrate nitrogen present in the soil was also suggested, with a peak in the late spring / early summer period and in one case, a nitrate accumulation in the summer.

(d) Organic Matter: Animal manure caused a greater build-up of soil organic matter under pasture than clover, the greatest improvement however being when both manure and clover were present together.

Earthworms: (a) The influence of clover on earthworm population caused a maximum increase of 300%. The manurial effect was decidedly less striking and exhibited a seasonal influence particularly in the "grass alone" plots.

Worm populations varied from ½ million to 4 million / acre.

The weight of worms varied from 1 cwt. to 22 cwt. / acre.

(b) Seasonal activity appeared to be largely dependent upon soil temperature and soil moisture conditions, with a peak occurring about the September - October period.

(c) A. Caliginosa and L. rubellus were the predominant species identified in the experimental area and showed consistent variation in their ability to withstand different environmental conditions, A. caliginosa appearing hardier than L. rubellus.

superior in every characteristic measured. From such results, the present-day emphasis on clover and the grazing animal in relation to pasture production appears fully justified. In fact, the establishment of a suitable clover or allied legume in the sward, combined with adequate attention to a uniform redistribution of the animal residues over the farm, is of paramount importance if a high level of soil fertility, as shown, and therefore maximum pasture production is to be achieved and maintained by the grassland farmers of this country.

it is this "adequate design" that is often so difficult to achieve. The problem of "practicability" is everlastingly confronting the research worker in an endeavour to achieve experimental adequacy in his particular study, that will supply data enabling the application of appropriate statistical treatment. Consequently statistical science, fully realizing this difficulty, has devised and is continually devising various combinations whereby many treatments can be satisfactorily incorporated in experimental designs which previously would have demanded considerably greater requirements in both land and material for accurate conclusions to be drawn. In other words, they are effectively overcoming the limitations presented by lack of space and labour found at many research stations and at the same time maintaining experimental adequacy and statistical accuracy.

An example of experimental inadequacy can be found in the present investigation viz., a design that was quite adequate for measuring pasture production fell far short of the requirements apparently demanded by soil studies, on which the latter was super-imposed. While herbage yields only varied by 4-5% between duplicates, soil determinations showed up to 100% variation.

Further evidence of the importance of design was presented in an interesting discovery revealed by the soil analyses. Although completely undetected by herbage data, a "fertility gradient", occurring at one end of the experimental area and influencing approximately four treatments, was immediately apparent from the soil phosphorus determinations. This annoying abnormality was consistently obvious right throughout the period of the investigation making interpretation extremely difficult. Another inexplainable abnormality was also exhibite by a "grass" plot (1AA) near the centre of the experiment. In both phosphate and pH determinations this area gave most irregular results which differed considerably from the replicate.

Any attempt at statistical analyses of the data obtained was consequently of doubtful worth and as would be expected proved fruitless. As a result only trends and tendencies could be drawn from the figures, although it was felt that in several cases such inferences were worthy thorough soil analyses at the commencement of an investigation; and as a tentative suggestion, an endeavour to achieve soil homogeneity, whether by preceeding treatment or by actual soil mixing, as a possible aid to fundamental soil research; if soil studies are to be most successfully incorporated in pasture trials.

In view of the criticism offered above, it is only fair to mention that the trial considered was only part of a major layout, a "mowing" and "grazing" trial, as mentioned in the section on "Experimental Area". As yield comparisons between these two sections are consistent, it is not suggested that the yield data obtained by "Grasslands" have been erroneous.

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presented below, as follows:-

ACID-SOLUBLE PHOSPHORUS (a modification of Egner's Method)

Procedure: 1 gm of air-dry soil which has passed a 1 m.m. sieve is transferred to a shaking bottle, and 50 c.c. of extracting liquid - prepared by diluting 10 c.c. of lactate buffer with 250 c.c. distilled water — followed by 1 hr. in a rotary shaker held at constant temperature 70° F. After extraction, the suspension is filtered through No. 30 or 40 Whatman filter paper giving a clear filtrate.

Of this, 10 c.c. or 25 c.c. (depending whether manure or no-manure plots were being analysed) is pipetted into a 50 c.c. volumetric flask, to which distilled water is added to bring the volume to 35 c.c. 10 c.c. of Molybdate solution is then blown in through the pipette to obtain thorough mixing followed by 5 c.c. of dilute Stannous Chloride solution - resulting in a total volume of 50 c.c. and the development of a blue colour. The solution is inverted several times for mixing and allowed to stand 5 or 6 minutes for full colour to develop, then read in a photometer. The reading obtained is then applied to a graph, to obtain "micrograms P/ml." and by calculation expressed in "mgm. PO_4/100 gm. of soil."

REAGENTS: LACTATE BUFFER: One half gram-molecule of pure calcium lactate is transferred to a tall 2 litre beaker and dissolved in a litre of boiling distilled water; One half gram-molecule of HCl is added; then the whole diluted to 2 litres plus a few drops of chloroform and adjusted to pH 4.8. (From this the extracting solution was prepared)

AMMONIUM-MOLYBDATE - HCl ACID: Dissolve 15 gm. of A.R. ammonium molybdate in about 350 c.c. of distilled water. 350 c.c. of 10N HCl was then added slowly with stirring. After cooling to room temperature it was diluted to 1000 c.c. with distilled water, mixed well, and stored in a black glass-stoppered bottle - prepared fresh every two months.

six weeks.

The dilute solution was made by adding 1½ c.c. of stock solution to 200 c.c. of distilled water - prepared fresh every four hours.

ADSORBED PHOSPHORUS ( )

Procedure: 1 gm. of air-dry soil was saturated with neutral NH_4Cl followed by shaking for one hour in 50 c.c. of 0.5N NH_4F. The suspension was then filtered and an aliquot (10 c.c.) taken. To this 15 c.c. of Boric acid (.8M) was added, followed by distilled water to make the volume up to 35 c.c. 10 c.c. of Molybdate reagent was then added, mixed by blowing from pipette, plus the 5 c.c. of dilute stannous chloride. After mixing and the period elapse for colour development, the reading was made in the photometer, as before.

REAGENTS: AMMONIUM FLUORIDE (0.5N): Dissolve 18.5 gm. of solid NH_4F in 1 litre of distilled water, adjusted to pH7 and stored in a wax-lined bottle.

BORIC ACID SOLUTION (8M): Dissolve 50 gm. A.R. Boric acid in 1 litre of distilled water.

AMMONIUM-MOLYBDATE - HCl acid: as for acid-soluble P determination.

STANNOUS CHLORIDE: as for acid-soluble P determination.

SOIL REACTION: From a sample of air-dried soil, one teaspoon is taken and diluted with 12 c.c. distilled water, left to stand for ¾ hour - to allow for "drift" - and then measured with a "Beckmann pH Meter".

POTASH: ( )

Procedure: A teaspoon of soil is levelled off and placed in a test tube, 10 c.c. of extracting solution added and the tube vigorously shaken for exactly 1 minute then filtered immediately through a Whatman No. 30 filter paper. Soil extracts from 3 or 4 samples are prepared in this way and 1 c.c. of each is placed in a 2 c.c.

Two drops of sodium Cobaltinitrite solution is added to each followed by 1 c.c. of 95% alcohol added slowly with repeated shaking. Five minutes are allowed for full colour to develop and then the potash concentration of the unknown is estimated by a comparison with the standards. For this purpose the holder is held about eye-level against a suitable background and the tubes containing the unknowns run alongthe row of standards until their place in the series is ascertained.

The standards form a well-defined series from 32 p.p.m. K_2O which gives a heavy yellow precipitate to 4 p.p.m. K_2O in which there is only faint turbidity. A blank may be used with advantage in the estimation of very low potash contents. It is noticeable that the heavier the precipitate the lighter the colour of the resultant suspension. This no doubt, is the basis of Spurway's Colour Chart for estimating potash content of extracts, but the making up of standards was found to be much more satisfactory. The estimation of high potash content is best carried out by diluting the soil extract 1:1 with distilled water and using 1 c.c. of this diluted extract for the test.

Comparisons should be completed as soon as possible after full development of colour (within 5 minutes) as colour fades rapidly in strong light. The estimation should not be made in sunlight.

<u>REAGENTS:</u> <u>SODIUM COBALTINITRITE SOLUTION</u>

Solution A: 25 gms. Cobaltous nitrate dissolved in 50 c.c. of distilled water with 12.5 c.c. of glacial acetic acid added to the solution.

Solution B: 120 gms. Sodium nitrite in 180 c.c. of distilled water.

210 c.c. of solution B are added to all of solution A and the nitric fumes evolved are removed by bubbling air through the liquid for several hours.

ively are prepared by dilution.

ACETIC ACID: The extracting solution is 1 c.c. of 1:7·5 acetic acid (1 of glacial acetic to 7.5 of water) made up to 130 c.c. with distilled water. 10 c.c. of this solution is used for extracting one level teaspoon of soil.

AMMONIA AND NITRATE NITROGEN ( )

Procedure: From fresh soil, after passing through ½" seive or broken up by hand if too wet, 150 gms. is taken representatively. 50 gms. for determination of moisture and 100 gms. for the preparation of the soil extract.

The 100 gms. is placed in a shaking bottle to which is added 100 c.c. of 2N KCl, sufficient 2N.HCl to bring the soil extract to the correct acidity (about pH 1.5) - in this case 10 c.c. - and water to make the volume up to 200 c.c. About 7 drops of toluene are added, followed by 2 hours shaking in a rotary shaker.

The whole contents are then transferred to a 24 cm. filter paper in one pouring, the first 20 - 30 c.c. of filtrate rejected, but the remainder kept and corked until required for determination.

AMMONIA: 100 c.c. of the above extract is made up to 300 c.c. with distilled water in a litre distilling flask. About 5 gms. magnesium oxide is added and 200 c.c. distilled over into a measured volume of N/50 acid. Bromo-cresol green is added and the excess acid is titrated with N/50 NaOH until the colour of the liquid matches an acetate buffer solution at pH 4.8 to which bromo-cresol green has been added.

NITRATE: The above volume of liquid in the distilling flask is again brought up to 300 c.c. with distilled water and about 2.5 gms. of Devarda's alloy added. The same volume as before is distilled into a measured volume of N/50 acid, the distillation being carried out slowly i.e. 1¼ - 1½ hours for 200 c.c. to distill over. Titrate as before.

Procedure: Digest 10 gm. of soil in a 500 ml. Kjeldahl flask with 30 ml. conc. H_2SO_4, 0.7 gm. HgO (or 0.65 gm. Hg) and 5 - 10 gm. anhydrous Na_2SO_4. Continue the digestion for 1½ - 2 hours. After cooling, add about 200 ml. distilled H_2O. When cold, add a pinch of zinc dust and an excess (about 100 ml.) of approximately 45% NaOH solution containing about 12 gm. K_2S per litre. Join the flask to the condenser by means of a Kjeldahl connecting bulb, taking care that the tip of the condenser tube extends below the surface of the standard acid in the receiving flask. Mix the contents of the Kjeldahl flask by shaking and collect about 150 ml. of distillate. Titrate the excess acid, using in this case a mixed indicator, with 0.01N alkali. Run a blank determination in exactly the same manner, but using about 0.2 gm. sucrose in place of the soil, to correct for any nitrogen contained in the reagents.

The percentage of nitrogen in the soil on the basis of a 10 gm. sample = (B - T) x N x 0.14, where B = blank titration in milliliters of standard alkali, T = actual titration in ml. of standard alkali, and N = normality of the standard alkali.

REAGENT: MIXED INDICATOR: Mix 10 ml. of 0.1% bromo-cresol green in 95% alcohol with 2 ml. 0.1% methyl red in 95% alcohol.

ORGANIC MATTER ( )

Procedure: To a clean and dry 8 by 1 inch pyrex test tube transfer 0.1961 gm. of powdered potassium dichromate and the sample, 0.5 gm. or less if high in organic matter (in this case 0.1 gm.). Samples containing chloride in appreciable amount should first be washed on a thin pad of ignited asbestos in a Shimer filter and the moist asbestos and soil transferred to the test tube. Mix the sample and the dichromate and wash down with 10 c.c. concentrated H_2SO_4. Have ready a bath made by heating to 205 - 210°C. a 100 ml. of conc. H_2SO_4 in a wide-mouth 250c.c. pyrex flask. Stir the contents of the test tube with a thermometer pushing down any charred particles and immerse the tube in the bath until the temperature of the recover all the residual chromic acid in 100 c.c. total volume. Stir into the cold solution about 5 gms. powdered sodium fluoride - a level teaspoon - and add 2 or 3 drops of indicator (0.5% solution of diphenylamine in conc. H_2SO_4). Titrate with 0.2N ferrous ammonium sulphate until the brilliant blue colour, which usually does not appear until the titration is started, fades to a muddy green with only a suggestion of blue. This end point is very sharp. If lessthan half of the dichromate added is indicated by the titration to remain, it is advisable to repeat the determination with a smaller sample.

Run a blank with a similar soil sample which has been thoroughly ignited to burn off all the carbon. Deduct from the titration figure with this ignited sample, that obtained with the sample not ignited; the difference corresponds to chromic acid reduced by the organic matter in the sample. In theory, 1 c.c. of 0.2N solution is equivalent to 0.0006 gm. of carbon or approximately 0.0012 gm. of organic matter as determined by this method with 90% recovery, but it is best to standardize the titrating solution against a similar soil of known organic carbon content.

REAGENTS: 0.2N FERROUS AMMONIUM SULPHATE Dissolve 19.61 gms. of the above crystals (powdered) in water containing 5 c.c. of conc. H_2SO_4 and finally diluted to 250 c.c. which should be approximately 0.2N. It is best to prepare the solution as required, as it will only last one or two days. To check the strength against potassium dichromate:- 0.1961 gms. of the latter dissolved in 100 c.c. of water containing 10 c.c. of conc. H_2SO_4 with 5 gms. sodium fluoride and diphenylamine indicator, should require 20.00 c.c. of 0.2N solution in a titration.

POTASSIUM DICHROMATE: Crystals of reagent grade, finely powdered and dried at 110°C. and kept in a small bottle in a dessicator.

SODIUM FLUORIDE: a pure salt (as powder) - its purpose being to improve the characteristics of diphenylamine as an indicator; the

DIPHENYLAMINE SOLUTION: Dissolve 0.05 gm. of diphenylamine in 10 c.c. of conc. H_2SO_4 and keep in a small bottle with dropper.

AGGREGATE ANALYSIS OF THE SOIL (50 gm. Samples in triplicate)

DEPTH 0"-2"

Diam.	No.	Wt.	%	Wt.	%	Wt.	%	Wt.	%
2 m.m.	10 I.M.M.	5.651 gms.	18.2	5.588 gms.	18.3	5.821 gms.	22.3	7.207 gms.	2[illegible]
1.2 m.m.	16 I.M.M.	6.505 gms.	21.0	5.246 gms.	17.1	5.061 gms.	19.4	6.629 gms.	2[illegible]
0.42 m.m.	40 I.M.M.	11.996 gms.	38.7	11.679 gms.	38.1	9.149 gms.	35.1	12.187 gms.	3[illegible]
0.25 m.m.	60 I.M.M.	4.094 gms.	13.2	4.799 gms.	15.7	3.512 gms.	13.4	4.518 gms.	1[illegible]
0.18 m.m.	80 I.M.M.	1.732 gms.	5.6	2.297 gms.	7.5	1.580 gms.	6.1	1.572 gms.	[illegible]
0.15 m.m.	100 I.M.M.	1.038 gms.	3.3	1.027 gms.	3.3	0.968 gms.	3.7	0.872 gms.	[illegible]

Total Percentage of Aggregates >0.15 m.m. diam. : 62.0% 61.3% 52.2% 65.9%

AGGREGATE ANALYSIS OF THE SOIL (50 gm. Samples in triplicate)

DEPTH 2"-4"

2 m.m. 10 I.M.M.	8.083 gms.	24.0	7.054 gms.	20.2	7.219 gms.	23.4	6.889 gms.	1
1.2 m.m. 16 I.M.M.	8.472 "	25.2	7.127 "	20.4	5.940 "	19.3	8.148 "	2
0.42 m.m. 40 I.M.M.	11.914 "	35.4	13.383 "	38.3	10.732 "	34.8	15.249 "	4
0.25 m.m. 60 I.M.M.	2.766 "	8.3	4.202 "	12.0	3.822 "	12.4	4.177 "	1
0.18 m.m. 80 I.M.M.	1.616 "	4.8	2.147 "	6.2	1.938 "	6.3	1.897 "	[illegible]
0.15 m.m. 100 I.M.M.	0.847 "	2.3	1.035 "	2.9	1.158 "	3.8	0.691 "	[illegible]
Total Percentage of Aggregates > 0.15 m.m. diam. :	67.4%		69.9%		61.6%		74.1%	

AGGREGATE ANALYSIS OF THE SOIL (50 gm. Samples in triplicate)

DEPTH. 4"-6"

Sieves.		Plot 1 AB		Plot 5 AB		Plot 1 BB		Plot 5
Diam.	No.	Wt.	%	Wt.	%	Wt.	%	Wt.
2 m.m.	10 I.M.M.	9.389 gms.	26.7	8.836 gms.	23.5	9.890 gms.	27.7	7.193 gms.
1.2 m.m.	16 I.M.M.	7.832 "	22.3	8.230 "	21.9	7.752 "	21.7	8.329 "
0.42 m.m.	40 I.M.M.	12.079 "	34.4	14.040 "	37.4	12.170 "	34.1	15.811 "
0.25 m.m.	60 I.M.M.	3.432 "	9.8	3.619 "	9.6	3.371 "	9.5	4.403 "
0.18 m.m.	80 I.M.M.	1.609 "	4.6	1.919 "	5.1	1.657 "	4.7	2.008 "
0.15 m.m.	100 I.M.M.	0.792 "	2.2	0.915 "	2.5	0.823 "	2.3	0.687 "
Total Percentage of Aggregates >0.15 m.m. diam.	:	70.3%		75.1%		71.3%		76.9%

AGGREGATE ANALYSIS OF THE SOIL (50 gm. Samples in triplicate)

DEPTH. 6"-9"

Sieves Diam.	Sieves No.	Plot 1 AB Wt.	Plot 1 AB %	Plot 5 AB Wt.	Plot 5 AB %	Plot 1 BB Wt.	Plot 1 BB %	Plot 5 BB Wt.	Plot 5 BB %
2 m.m.	10 I.M.M.	3.453 gms.	9.9	1.408 gms.	4.1	6.406 gms.	19.9	8.060 gms.	21.3
1.2 m.m.	16 I.M.M.	6.977 "	20.0	3.604 "	10.3	6.675 "	20.8	7.958 "	21.1
0.42 m.m.	40 I.M.M.	16.656 "	47.9	17.905 "	51.2	11.988 "	37.3	14.395 "	38.1
0.25 m.m.	60 I.M.M.	4.907 "	14.1	6.985 "	20.0	3.836 "	11.9	4.584 "	12.1
0.18 m.m.	80 I.M.M.	1.944 "	5.6	3.203 "	9.2	2.155 "	6.7	1.845 "	4.9
0.15 m.m.	100 I.M.M.	0.869 "	2.5	1.819 "	5.2	1.053 "	3.4	0.956 "	2.5
		31.993		29.902					

Total Percentage of Aggregates >0.15 m.m. diam. : 69.6% 69.8% 64.2% 75.6%

ACID-SOLUBLE PHOSPHORUS (expressed as lbs. P_2O_5/ac. approx.)
(Average of duplicate plots.)

Treatment.	12/3/48	23/6/48	9/8/48	12/9/48	8/10/48	18/10/48	8/11/48	8/12/48
Grass only	50	51			46			
Grass + Clover	20	13			12			
Grass + Clover + Super	28	37	44	39	29	47	54	41
Grass + Clover + Lime	21	18			18			
Grass + Clover + Super + Lime	57	83	73	72	74	81	94	82
Grass + Super + Lime	91	120	131	124	113	129	134	127
Grass only + Dung & Urine	119	106			104			
Grass + Clover + Dung & Urine	116	83			77			
Grass + Clover + Super + D. & U.	144	119	122	119	122	140	140	136
Grass + Clover + Lime + D. & U.	94	80			79			
Grass + Clover + Super	130	137	133	127	128	140	157	144
Grass + Super + Lime + D. & U.	164	173	179	169	165	189	191	176
		3mths. after application of 3 cwt. Super.	1mth. avter 3cwt. Super.	2mths. after.	3mths. after.	1 wk. after 4 cwt. Super.	1mth. after.	2mths. after.

ADSORBED PHOSPHORUS (expressed as lbs. P_2O_5/ ac. approx.)
(average of duplicate plots)

Treatment	12/3/48	23/6/48	9/8/48	12/9/48	8/10/48
Grass only	107	115			115
Grass + Clover	68	70			64
Grass + Clover + Super	83	104	137	120	110
Grass + Clover + Lime	47	49			55
Grass + Clover + Super + Lime	132	159	160	156	156
Grass + Super + Lime	168	235	242	234	211
Grass only + Dung & Urine	194	183			187
Grass + Clover + Dung & Urine	205	169			166
Grass + Clover + Super + D. & U.	222	214	240	232	237
Grass + Clover + Lime + D. & U.	153	148			187
Grass + Clover + Super + Lime + D.& U.	203	218	226	224	234
Grass + Super + Lime + D. & U.	237	263	263	253	253
		3mths. after 3 cwt. Super	1mth. after 3 cwt. Super	2mths. after	3mths. after

SOIL pH DETERMINATIONS.

	1BA	2BA	3BA	4BA	5BA	6BA	1AA	2AA	3AA	4AA	5A
12/3/48	7.1	7.05	6.75	7.05	6.85	7.2	6.7	5.9	5.95	6.6	6.
23/6/48	6.95	6.3	6.1	6.7	6.6	7.2	6.6	5.85	5.9	6.75	6.
8/10/48	6.9	6.5	6.3	7.0	6.95	7.1	6.6	5.9	5.8	6.8	6.

12/3/48	7.1	6.6	6.9	6.5	6.55	6.7	6.8	6.5	6.4	6.0	5.
23/6/48	7.1	6.5	6.5	5.9	6.0	6.6	6.85	6.5	6.7	6.0	5.
8/10/48	7.1	6.8	6.9	6.0	6.1	6.5	6.8	6.6	6.8	5.75	5.
	6BB	5BB	4BB	3BB	2BB	1BB	6AB	5AB	4AB	3AB	2A

Grass only	:	48- p.p.m.	48- p.p.m.	48-	32+
Grass + Clover	:	16	48	16+	48-
Grass + Clover + Super	:	32	32	16+	16+
Grass + Clover + Lime	:	32+	32	48-	32
Grass + Clover + Super + Lime	:	16+	16+	16+	16
		BA	BB	BA	BB
Grass + Super + Lime	:	32+	48-	32	32
Grass + Manure	:	96-	72	72-	48+
Grass + Clover + Manure	:	96-	96-	72+	72+
Grass + Clover + Super + Manure	:	72+	96-	72	72
Grass + Clover + Lime + Manure	:	48+	72+	72+	72
Grass + Clover + Super + Lime + Manure	:	72	72+	48	72
Grass + Super + Lime + Manure	:	72-	72	72	48+

AMMONIA & NITRATE NITROGEN IN THE SOIL (0"-2")

(expressed as parts/million)

		19/8/48.		22/10/48.		22/12/48
		Ammonia N.	Nitrate N.	Ammonia N.	Nitrate N.	Ammonia N.
Grass only	:	0 p.p.m.	7 p.p.m.	24	14	11
Grass + Clover	:	7 "	1 "	25	13	28
Grass + Clover + Super	:	10 "	1 "	28	11	30
Grass + Clover + Lime	:	14 "	1 "	34	11	20
Grass + Clover + Super + Lime	:	13 "	9 "	44	4	43
Grass + Super + Lime	:	7 "	7 "	35	4	28
Grass + Manure	:	16 "	1 "	36	7	26
Grass + Clover + Manure	:	18 "	38 "	58	26	48
Grass + Clover + Super + Manure	:	25 "	47 "	32	38	41
Grass + Clover + Lime + Manure	:	39 "	55 "	25	29	34
Grass + Clover + Super + Lime + Manure	:	22 "	28 "	37	35	38
Grass + Super + Lime + Manure	:	21 "	1 "	41	14	31

	12/3/48		12/1/49		
	AA	BB	AA	BB	
Grass only :	4.19%	4.54%	5.05%	4.60%	
Grass + Clover :	4.16	4.72	5.39	5.52	
Grass + Clover + Super :	4.77	4.38	5.62	5.29	
Grass + Clover + Lime :	4.54	4.14	5.52	5.62	
Grass + Clover + Super + Lime :	4.38	4.42	5.39	5.29	
Grass + Super + Lime :	4.54	4.48	5.17	5.17	
	BA	BB	BA	BB	
Grass + Manure :	5.63	4.77	7.36	5.52	12.8
Grass + Clover + Manure :	5.46	5.29	7.36	5.86	13.22
Grass + Clover + Super + Manure :	6.04	5.86	7.02	6.89	
Grass + Clover + Lime + Manure :	5.69	5.98	6.67	6.78	
Grass + Clover + Super + Lime + Manure :	5.29	5.80	6.78	6.55	
Grass + Super + Lime +Manure :	4.72	5.41	5.39	6.21	

EARTHWORM ANALYSIS (0"-4")

(average of duplicate plots)

		19th May, 1948.				8th August, 1948	
Treatment.	No./sq.ft.	Total Weight.	Average Wt.	lbs./ac.	No./sq.ft.	Total Wt.	Avera
Grass only :	13	2.11 gms.	0.16 gm.	203	22	4.8 gms.	0.2
Grass + Clover :	32	6.76	0.21 "	648	78	20.0	0.2
Grass + Clover + Super :	54	10.78	0.20	1035	56	15.9	0.2
Grass + Clover + Lime :	39	10.45	0.27	912	91	26.6	0.2
Grass + Clover + Super + Lime. :	50	15.11	0.30	1449	68	18.0	0.2
Grass + Super + Lime :	16	3.13	0.20	300	33	8.4	0.2
Grass + Manure :	21	3.46	0.17	332	51	12.3	0.2
Grass + Clover + Manure :	37	10.76	0.29	1028	83	26.8	0.3
Grass + Clover + Super + Manure :	34	11.77	0.35	1179	72	23.9	0.3
Grass + Clover + Lime + Manure :	46	11.91	0.26	1143	72	23.3	0.3
Grass + Clover + Super + Lime + Manure :	48	16.10	0.34	1595	80	25.5	0.3
Grass + Super + Lime	8	1.72	0.21	166	65	16.5	0.2

EARTHWORM ANALYSIS (0"-4")

(average of duplicate plots)

		15th November, 1948				25th January, 1		
		No./sq.ft.	Total Weight.	Average Wt.	lbs./ac.	No./sq.ft.	Total Wt.	Average
Grass only	:	9	1.42 gms.	0.16 gm.	136	7	1.31	0.19
Grass + Clover	:	49	13.57 "	0.28	1302	26	8.78"	0.34
Grass + Clover + Super	:	44	12.45	0.28	1194	26	8.75	0.33
Grass + Clover + Lime	:	46	16.19	0.35	1553	26	8.83	0.34
Grass + Clover + Super + Lime	:	43	10.58	0.25	1015	29	8.47	0.29
Grass + Super + Lime	:	18	4.62	0.25	443	7	0.90	0.13
Grass + Manure	:	34	10.63	0.31	1020	18	3.53	0.19
Grass + Clover + Manure	:	53	24.41	0.46	2342	43	17.44	0.41
Grass + Clover + Super + Manure	:	54	22.09	0.41	2119	38	10.40	0.28
Grass + Clover + Lime + Manure	:	67	23.42	0.35	2247	34	9.50	0.28
Grass + Clover + Super + Lime + Manure	:	68	24.02	0.35	2305	37	10.95	0.30
Grass + Super + Lime + Manure	:	25	7.6	0.30	729	24	3.77	0.16

IDENTIFICATION OF ADULT WORMS

FROM SELECTED PLOTS. (number of)

Plots.	8th August, 1948.		15th November, 1948.		25th J
	Lumbricus sp.	Allolobophora sp.	Lumbricus sp.	Allolobophora sp.	Lumbricus sp.
1AA :	1	7	1	4	Non-mature
1AB :	2	6	Non-mature	3	"
4AA :	24	17	12	9	4
4AB :	35	16	16	14	9
1BA :	2	13	4	12	Non-mature
1BB :	5	21	7	18	1
2BB :	-	-	20	12	9
3BB :	17	9	13	9	3
5BA :	25	13	18	20	6