THE ROLE

of

THE ROOTS OF SOME GRASS AND CLOVER SPECIES

in the

IMPROVEMENT

of the

SOIL STRUCTURE

of a

TOKOMARU SILT LOAM.

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A thesis presented at Massey Agricultural College in part fulfillment of the requirements for the Degree of Master of Agricultural Science, University of New Zealand.

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SECTION I.

INTRODUCTION.

It has long been realised that grassland has a beneficial effect on the fertility of soil. This is not only the case with the natural grasslands of the world which are found in areas of limited precipitation and cold winters, and which have provided a rich harvest of grain products for many years after their initial ploughing. It is also so in those other agricultural areas where forest was the natural cover, and where it has now been found necessary to alternate the exhaustive periods of crop growing with restorative periods in pastures.

The improvement in soil fertility due to the growth of the grass-clover-herb mixtures is partially due to the build up of nitrogen through both free-living and symbiotic nitrogen fixing organisms (78). It can also be the result of the supplemental feeding of the grazing animals. But some of the value of the pasture rest period has been shown to be due to the more suitable arrangement of the soil particles following this period in pasture. These primary particles are normally gathered together into aggregates or clods or crumbs, and the size distribution and the stability of these determines the soil structure. Davies (11) goes so far as to say that the chief fertility effect of the grass/legume ley is per medium of soil structure. Common observations together with measured improvements in crumb structure in many recent experiments (50, 58, 75, 39, 44) have demonstrated these changes in the soil. Other investigations (3, 56, 53) have shown the beneficial effect of this improved structure on the crops subsequently grown.

On the other hand in some of the world's main grain growing regions, although the yields remain payable, excessive cropping without any restorative periods has reduced the structural condition of the soil to a stage where in some parts soil erosion has become so serious that remedial measures are difficult to apply. The "Dust Bowl" of the United States is a case in point, and it seems likely that some of the world's desert areas have been extended as a result of similar circumstances.

Little, however, is known of the relative value of grasses and legumes in the maintenance of good soil structure, nor have many of the grass species been evaluated in terms of their structure building ability. Russian (26) and English (39) workers differ in their conclusions as to how long the restoration of structure by grassland takes, the former contending it is complete in two to three years, the latter considering that it is still far from completed after 25 years. No indication is available as to what happens under New Zealand conditions, although with our present proportion of arable land to pasture, and with the short time that any one paddock is under the plough, the problem is not of major importance in our agricultural areas. However, it is probable that with increasing population we shall have to increase arable crop production to an extent not yet known in New Zealand. When that happens knowledge of the value of grasses and clovers in structure restoration will be imperative, as it is now on many of the intensively cropped soils of the world.

This experiment was designed to investigate some of the unanswered problems outlined by Davies (11) in 1949, in particular:-

"1. What is the role of grasses, legumes and herbs in relation to soil structure?

2. Is a quickly decomposing root system such as is found in the ryegrass/white clover ley better adapted to soil up-building than a slowly decomposing turf?

3. Have the tufted grasses as ryegrass, cocksfoot and timothy any advantage or disadvantage in relation to soil conditions over the rhizome-forming grasses?"

As no suitable plots of single species were available on soil of low structural stability, it was decided to sow down such plots and follow the changes in structure and in root growth during a period of about two years. To gain further information about the effect of the sub-aerial parts of the grasses and clovers, a subsidiary pot experiment was designed to give some information on the rate of break-down of grass and clover roots in the soil and to measure what effect this had on the stability of the aggregates in that soil.

The paucity of information on methods of measuring soil structure in New Zealand meant that careful consideration had to be given to techniques used elsewhere. Consequently, much of the early work in the investigation consisted in developing a satisfactory technique for the prevailing conditions. Because of the importance of being able to obtain repeatable results in line with field conditions, the work leading up to the method finally adopted is fully reported in Section III.

SECTION II

REVIEW OF LITERATURE.

A. Soil Structure

As already mentioned, the development of soil structure is largely due to the formation of stable aggregates of primary particles. Baver (12) in 1948 considered that this cementation was caused by the soil colloidal material which is composed of at least three distinct groups:

(i) Clay particles;

(ii) Inorganic colloids such as oxides of iron and alumina;

(iii) Organic colloids.

The properties of clay make it a very important factor in aggregate formation, but the importance of colloidal iron has not been evaluated sufficiently to date. However, these two effects will not be discussed in detail as the role of plant roots in aggregate formation is unlikely to be operative in this direction. There is no doubt that the effects of organic colloids in developing stable aggregates are widespread. The findings of Martin (47, 48) McHenry and Russell (43) and Elson and Lutz (15) are typical of those of many others who have found that the quantity and quality of organic matter additions to soils have had pronounced effects on their structural changes. It is also known now that organic substances other than colloids can act as binding agents in the formation of water stable soil granules. (21, 41, 65, 88, 36). These consist of cells of micro-organisms and their secretory products such as mucus, slime or gum produced during growth (85). Other materials such as polysaccharides, synthesized by certain soil micro-organisms are known to improve the aggregating propensities of soils. Martin and Waksman (46) found that the more readily the organic matter decomposed, the greater was the effect on aggregation. In the case of decomposition by fungi, the extensive mycelial growth caused a mechanical binding of the soil particles in addition to aggregation from synthesized organic compounds.

Many investigators have found that a high state of aggregation may be produced by the addition of various organic materials to the soil. These substances are metabolites and are being built up and broken down continuously by biological means (62). The speed of decomposition depends largely on the same factors that determine the nutrition of the plant. So that the maintenance of good structure is therefore dependent on a continuous supply of organic matter or on the presence of aggregating substances capable of withstanding rapid breakdown by biological or other means. These latter are not normally present naturally but have been synthesized artificially, the one best known in New Zealand being Krilium (23).

Increased stability of soil aggregates formed from worm casts has been reported by Dutt (14), Hopp (25), Swaby (88) and Bakhtin and Polsky (1). The reasons for this have not been worked out but are thought to be due to mucilages produced either by the worm or by bacteria in its gut (69). Worm casts on pasture were found to be more stable than those from arable land indicating that the composition of the organic matter in the diet of the worms was different in each case. However, the effect of the worms was small compared with the effect of a 3 year ley. Watkin (95) found no definite trends in size distribution of soil aggregates in samples taken from plots having big differences in worm populations.

Nikolsky (55), among many others, considers that in a pasture, the improvement in soil structure is at least partially due to the return of organic matter both from ungrazed aerial parts and from the roots to the soil. As Baver (4) states, there is no satisfactory explanation as yet of the nature of the beneficial root effects. Nikolsky suggests that the root hairs serve to bind mechanical elements together and that the humus produced by the enhanced biological activity of the rhizosphere cements the more finely divided particles.

He postulates the formation at this stage of a water-stable mass and its simultaneous breakdown into granules by the action of root pressure and temperature changes. Sekera and Brunner (79) maintain that the smaller aggregates are composed of particles bound by colloidal cements, and that the larger aggregates are held together by living matter such as root hairs and fungal mycelia. Russell (69) agrees that the larger clusters are probably held together by roots, but is not sure whether the smaller granules are the result of direct action of the living material such as root hairs and micro-organisms or of biproducts of their life and death. Jacks (26) states that the most active part of a grass crop in aggregate formation is the root system which is not only the source of much of the humus which cements the soil particles into aggregates, but also has a mechanical effect in breaking up the clods and preventing them from coalescing. Keen's (34) conclusions in 1949 were similar. He says "In part, structure is mechanically caused by the roots pushing the soil particles into closer contact. In general, grasses would be expected to be more efficient in this respect than legumes because their total root length is much greater. Some form of cementing material, organic or inorganic or both, is involved in the water stability of the crumbs formed. Among agents that are responsible for this are the decomposition products of dead roots, the shedding of root caps in growth, siliceous compounds from root decay, lignification of roots into resistant compounds, and exudation from the living roots."

Baver (4) recalls that the earliest explanation of the effect of a grass sod was based on the pressure exerted by the growing roots, which effects a separation of the particles adjacent to the root and the pressing together of these units into aggregates. The penetration of sufficient root hairs or roots throughout a clod causes the formation of granules. One of the more recent suggestions is that granulation is accomplished by changes in moisture in the vicinity of the root system as a result of water uptake by the plant. This produces localized dehydration which brings about shrinkage and the formation of surfaces of fracture. It seems plausible to conclude that hypothetical materials produced during root growth and decay stabilize any aggregates that are formed. M.B. Russell (75) describes the effects of sod-crops in very similar words.

Bradfield (quoted by Jacks (26)) believes that the distribution of humus in the soil is more important than its quantity. He considers that grass roots provide the ideal distribution. Normal applications of farmyard manure are too localised, while tillage operations tend to give too high a degree of dispersion.

A perennial grass crop is generally considered to be superior to any other plant cover in the development of aggregation, but the effect of legumes is considerable and has been compared with that of grasses under a number of conditions. Several Russian investigators have been quoted by Jacks (26). Pavlov found that the percentage of water stable aggregates under old irrigated meadow was far superior to that in soils which had carried clover and lucerne for up to six years. Savvinov and Varobieva found no advantage for crested wheat grass over lucerne on steppe soils in Russia. Iovenko considers that legumes produce a "cloddy" structure throughout the entire root-inhabiting layer. Grasses, especially ryegrass produce a well-developed medium to fine granular structure, restricted however to the top 12-15 inches.

Shaw (80) at Ohio on Paulding clay found that continuous blue-grass produced a higher state of aggregation than continuous lucerne and this is confirmed by similar experiments at Iowa by Wilson and Browning (103) on Marshall silt loam. Both Gèltser (20) and Tysganov (91) record poor structure forming capacity in lucerne and other legumes compared with grasses.

In Uganda, Martin's (50) investigations indicate that the root systems of legumes are not so valuable in crumb formation as are those of grasses.

On the other hand, Ward (94), also at Iowa, recorded that "legumes (lotus corniculatus and three lespedeza species) were superior in three growing seasons to the prairie grasses on the Weller silt loam on a basis of their increases in aggregation". He considered that the degree of change manifested by a legume or grass was related to soil type.

The effect of individual grass and clover species used separately and together has been investigated by a number of workers. The majority of these have reported on results from the cropping areas of Russia and the United States. Tysganov (91) found that rapidly growing brome grass was an excellent structure former even in its first year. Agropyron tenerum had its maximum effect in its second year and A. cristatum (crested wheat grass) in its third year. Stevenson and White (86) in comparing the effects of crested wheat grass, brome grass and slender wheat grass found they increased the size of soil aggregates in that order. They concluded that the older and tougher root fibres were more efficient structure formers than the slender, easily decomposed roots. Pavlychenko (61) placed these three grasses in the same sequence, but there was no appreciable effect at depths exceeding four inches. Brome grass produced the greatest amount of underground material in the first two years, but at the end of four years, underground material from crested wheat grass exceeded that of brome grass and still more that of slender wheat grass. He suggested the soil-binding equivalent, i.e. the product of the length in centimetres of the roots per cubic centimetre of soil and their tensile strength in grams, as a measure of the value of a grass in structure improvement. These three grasses were placed in the same order for soil-binding equivalents. He considered, however, that the depth of root penetration and the length of time that the land had remained in sod were important additional factors. McHenry and Newell (44) found no difference in percentage of water stable aggregates on Butler silty clay loam soil on which brome grass and crested wheat grass had been growing for 7 years. Significant differences in structure development between native pasture species in North America have been obtained by McHenry and Newell (44), Pavlychenko (61) and Ward (94) but there is considerable disagreement between them in the placing of the species, depending on the soil type, the depth of sampling and the length of time since the land was sown down.

Very little work has been done to compare the effects of the temperate climate pasture species as soil aggregation improvers. McHenry and Newell (44) included Poa pratensis and Dactylis glomerata in their series but found no significant difference between them after seven years. Sarakhov (76) found that Italian ryegrass was relatively ineffective in the North Caucasian foothills in comparison with English ryegrass, brome grass and lucerne. Orchiston (59) found that on a silt loam in Canterbury, soils growing perennial and short rotation ryegrass were significantly higher in water stable aggregates than soil growing Italian ryegrass. In each case the grasses were sown with white clover and used for fodder conservation purposes. Williams (102) has found at Hurley that different grass species under field plot conditions have given statistically significant differences in the build up of water stable aggregates. These differences are related to the quantity of root material developed in the different swards.

B. Root Development and Deterioration.

Weinmann (100) in his recent review has indicated the importance of various environmental factors on the development of grass roots. The effects of nutrients and fertilizers differ with the other environmental conditions under which the various investigations have taken place, but in general can cause marked changes in the distribution and quantity of roots present. Soil texture also affects root development mainly by restricting growth in compacted sub-soil layers. Extremes of soil moisture inhibited root growth which was generally encouraged by "a relatively low water content so long as good growth was ensured." (97). Changes in root form and growth have been observed also as a result of temperature changes.

Weinmann records many examples of the effect of defoliation on root growth, and in practically all cases the more frequent cutting or grazing led to a decreased yield of roots. Individual species however, respond differently to such defoliation as illustrated in Table I adapted from Jacques (28).

<u>TABLE I</u> Comparative Yields of Air Dried Roots from Different Cutting Treatments.
(Calculated on basis of Certified Cocksfoot = 100)

Species	Cut Weekly	Cut two-Weekly.	Cut three-Weekly.	Uncut.
Certified Perennial Ryegrass	179	274	170	308
Uncertified Perennial Ryegrass	124	207	140	267
Certified Italian Ryegrass	120	306	164	306
Certified Cocksfoot	100	100	100	100
Totals calculated on basis: weekly cut = 100	100	236	355	825

Since Weinmann's review a number of investigations have confirmed and elaborated previous work on the effect of environment on root development. Typical of these is the report from Fox et al (18) on five Nebraska soils where both physical and chemical characteristics of those soils were found to be related to the distribution of grass roots.

Weaver and Zink (98) have commented on the dearth of information on the longevity of grass roots. A similar position exists in the case of legumes. Sprague (84) and Stuckey (87) found that with grasses of temperate climates between fifty and one hundred per cent of the root systems were replaced each year. Yen (108) observed marked deterioration of both clover and grass roots during the summer months. Sloughing of the cortex was used in the grasses as an indication of deterioration and occurred in up to 100% of the old roots. In the clovers the tap root showed signs of disintegration before the plants were a year old. There appears to be considerable variation among species in regard to root deterioration, while there is ample evidence that variations in environmental conditions such as soil moisture and rates of defoliation can affect the longevity of grass roots (5, 100). The roots of grasses and clovers in established pastures therefore can be expected to provide a continual and fairly regular supply of organic matter to the soil. In addition the root hairs of both grasses and clovers are a further source of supply of organic matter and almost certainly give a very intimate distribution of that organic matter throughout the soil. Although it has generally been considered that root hairs are transient, it has been noticed that they appear to be relatively longlined with many pasture species (12). However their survival can be no longer than the cortex of the roots.

In the establishment period of grasses, the plants are maintained by the seminal root system and a small contribution to the soil organic matter occurs when this system deteriorates within a few months of germination and establishment. No deterioration of the main root system of autumn sown pasture plants was found by Yen (108) until the early summer following sowing.

Variation in root form and yield between species growing under identical conditions has been demonstrated by Weaver (96) Jacques (31) and many other investigators. These differences are sufficiently great to produce a very big range of root patterns in the soil. To avoid variation from these factors in this investigation, care was taken to provide as identical environmental conditions as possible for each species. The plot area was small and compact, the site showed evenness in soil type, and defoliation was done with a mower, so that effects of stock through trampling, palatability, and dung and urine return were avoided.

SECTION III.

EXPERIMENTAL METHOD.

A. GENERAL

The experiment consisted in taking samples at intervals for the determination of

(a) the structural condition of the soil and

(b) the root development in the soil

from the following six field - plot treatments, sown in April, 1952

1.	Chewings fescue, Festuca rubra var. fallax.	CH
2.	Perennial ryegrass, Lolium perenne	PR
3.	Cocksfoot, Dactylis glomerata	CK
4.	White clover, Trifolium repens	WC
5.	Red clover, Trifolium pratense	RC
6.	Control, bare ground	BG

The above abbreviations have been used in the following pages where reference is made to the different treatments.

In April 1953 a further series of subsidiary plots was sown to provide material for a more complete range of root determinations and to supplement the information on structure. The treatments in this case were the above six together with (1) a plot sown with Italian ryegrass, IT, and (2) a plot treated with Krilium, KR.

B. The Experimental Area

The site chosen for the experiment was on the Crop Demonstration Area, Massey Agricultural College, and had been under intense cultivation and cropping for three years, having visibly lost structure during that time. The history of the area for the previous four years was:

1951-52	Maize for greenfeed.
1950-51	Kale (interrow cultivated)
1949-50	Kale (interrow cultivated)
1948-49	Temporary pasture

Prior to that it had been in permanent pasture of dominant Agrostis tenuis and Anthoxanthum odoratum for many years. The soil type is classified in Soil Bureau Bulletin No. 5 (54) as Tokomaru silt loam. It is gently sloping and is situated on a terrace of the Tiritea stream about 40 feet below that reported on in detail by Fife (17). Mechanical analysis showed that 3.8% of the soil was retained on a 2 mm. round holed sieve, and, from Table II which gives the percentage analysis of the remaining fine earth, it will be seen that only 2.6% was retained on a sieve with apertures 0.2 mm. in diameter.

TABLE II Mechanical analysis of 0-6 inch soil sample from Experimental Area. Percentage Composition of Oven-dry Soil.

Coarse Sand	Fine Sand	Silt	Clay	Loss by Solution	Loss by Ignition
2.6	50.2	22.3	22.4	0.7	7.9

The area was poorly drained in its natural condition, and in 1948 had been tile drained at intervals of approximately 30 feet to enable crops to be successfully grown.

During February 1952, a suitably uniform patch about seventy feet square was selected on the basis of the evenness of growth of the maize.

The latter was then pulled and carted off, and the area rotary-hoed with a Ferguson tractor and rotovator to a depth of six inches in two directions. It was then rolled with a heavy Cambridge roller using a seventy foot drawbar of No. 8 fencing wire to avoid uneven consolidation through running the tractor wheels over the plot area. After being hand raked to level up irregularities it was allowed to settle for nearly three weeks. During this time some weed seed germination occurred and the surface was cleaned up with a small B.M.B. Cultivator set to cut the seedlings off just under ground level. After a further raking and rolling, the area was ready for sowing.

C. Layout of Plots.

The layout of the plots was considered very largely from the point of view that statistical examination of the results was desired. McHenry and Newell (44) found that with twelve replications they were able to detect a difference between means of about 15% but they used large plots with consequent lack of uniformity. Ward (94) found that with plots replicated from five to ten times, significance of treatment differences varied with soil type, but the detectable difference appeared to be in about the same category. No other published data were available to give an indication of the range of structural effects likely to be produced by pasture species, especially those grown in New Zealand. The number of replications was also limited by the number of samples that could be dealt with in root development studies and in the determination of structure. As far as differences in root characteristics between species are concerned Jacques (29) recorded marked differences between species in root yield, and, despite the considerable variation that he found from sample to sample, it was not anticipated that it would be difficult to show significant differences between them. The plot size was reduced to the minimum necessary to provide adequate sampling space, and a randomized block experimental design was employed in which each treatment was replicated ten times, as illustrated in Fig. I. This design took into account the need for placing each plot in the same position relative to the tile drains running through the area, and at the same time the need for blocks to be as compact as possible. The design also made possible a comparison of two fertilizer treatments, but these were not proceeded with.

The necessity for keeping the whole plot area as small as possible was realised not only from the point of view of uniformity but also so that the plots could be kept in a weed free condition.

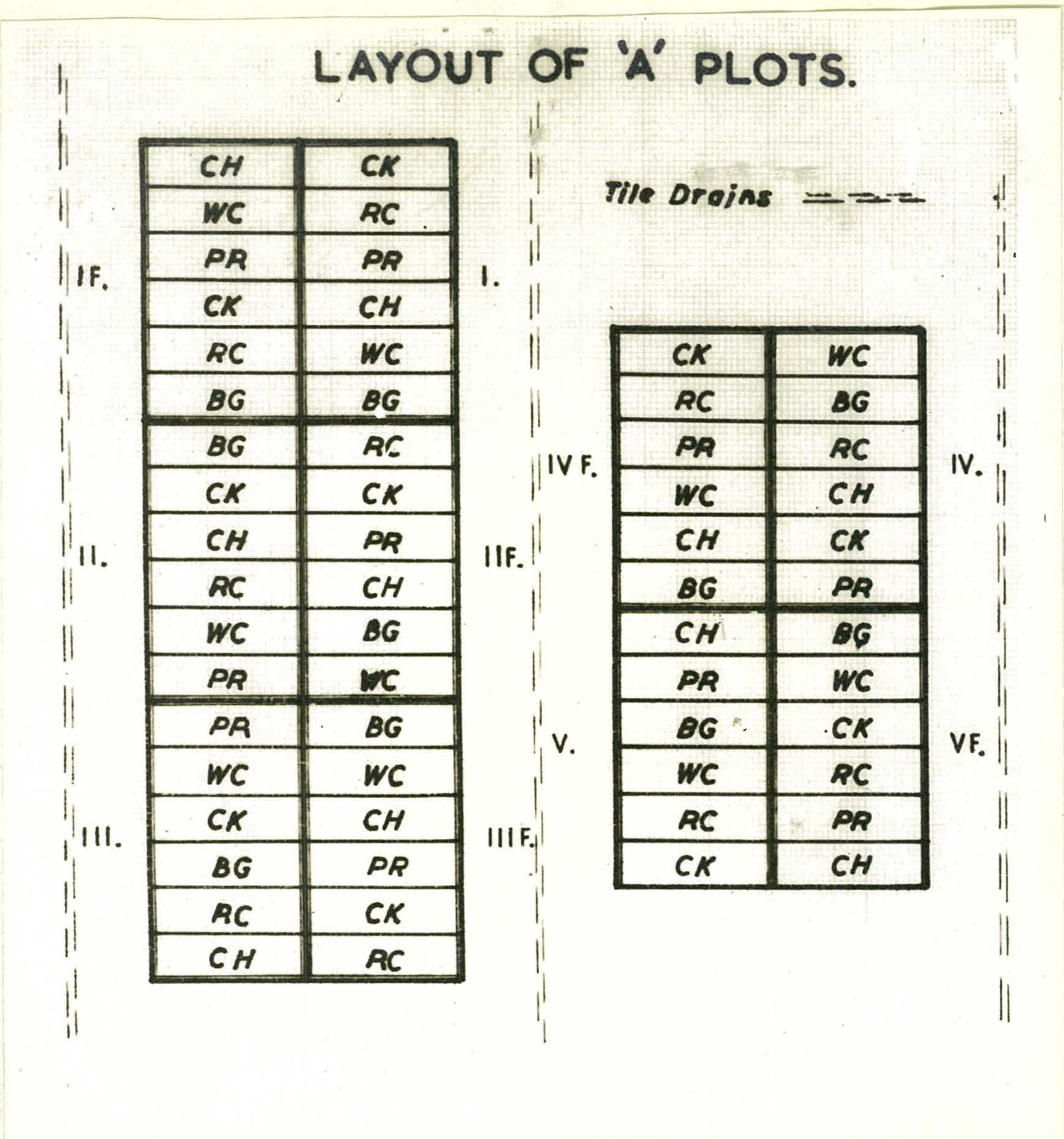

FIGURE 1 (a)

Diagram showing the layout of the "A" plots in relation to existing tile drains. The blocks are indicated by the numbers alongside.

FIGURE 1 (b)

Photograph taken immediately after sowing the "A" plots with Blocks V and VF in the foreground and part of Block I on extreme left. Cambridge roller marks are still visible on headland in foreground.

D. Establishment and Routine Care.

After the final cultivation of the area, namely Cambridge rolling, the plots were pegged out. Suitable lengths of 3" x 1" timber were used to delineate each plot as it was being sown. Seed of cocksfoot, perennial ryegrass, white clover and red clover were of Pedigree origin and the Chewings fescue from a high quality line. All were obtained from Grasslands Division, D.S.I.R. (see appendix I.) On April 1st 1952 the seed was sown by hand at heavy rates to ensure a dense and even strike and each plot was immediately raked over to cover the seed, most of which had fallen into the indentations left by the roller, as also had the 2 cwt. per acre of serpentine superphosphate applied with the seed.

Satisfactory establishment was obtained, but with all species except perennial ryegrass considerable hand weeding was necessary to maintain pure swards of the species sown. This was particularly so in the early stages of the white clover and Chewings fescue plots and to a lesser extent with the cocksfoot. <u>Poa annua</u> was the main impurity, although <u>Holcus lanatus</u> and <u>Coronopus didymus</u> were also prevalent. Weeding consisted in removing them with the least possible disturbance of the soil. A sharp pocket knife was found most suitable for the purpose. The bare ground plot was kept relatively free from vegetation but as time went on an increasing growth of <u>Rumex acetosella</u> occurred, and could not be completely controlled. The method here was to scrape the surface with a very sharp hoe severing the vegetation on or just under the surface of the soil. Altogether, the maintenance of the plots in a weed-free condition took many hours of regular weeding even when well established. To discourage the ingress of white clover into the grass swards, and weeds and grasses into the clover swards, growth was allowed to proceed to a height of one foot or more before being cut down to the six inch level.

In order to maintain growth satisfactorily on all plots, artificial fertilizers were applied whenever the appearance of the herbage indicated it. All plots received the same fertilizer application. (See Appendix II.)

Wherever necessary the herbage was cut and removed from the plots. As an indication of the thrift of the species concerned, it was weighed and sampled for dry matter determination. Several methods were used in cutting. An ordinary lawn mower was tried initially but could not be set to cut at a uniformly high level. This was replaced with the sickle mower of the Gravely Tractor at the next cutting but this machine would not handle the heavy growth at the time. Finally a similar machine, the Allen, was made available by Grasslands Division and proved highly satisfactory. It has a rigid cutter bar which can be maintained at a constant height very easily. The 3 ft. blade was just right to completely cut one plot at one sweep. The cut herbage was raked off each plot, collected in a canvas sheet and weighed by spring balance. Yields of dry matter on an acreage basis are recorded in Appendix III. They indicate that the growth from the plots was comparable with that occurring under plot conditions at Grasslands Division.

After each cutting the edges of the plots were trimmed to prevent the spread of species from one plot to another. White clover in particular was difficult to control.

E. Subsidiary Plots.

The initial samplings of the main plots for structure determinations took place four months and 8 months after sowing. These samplings were intended to enable a satisfactory technique of structure measurement to be worked out. It was not realized that differences between the treatments would show up at such an early stage and therefore root yields were not determined at the time of these early samplings. In order to gain some knowledge on the early root behaviour of the species, it was decided to sow down some subsidiary plots in the following autumn especially for this purpose.

The same species were used with the addition of Italian ryegrass and a treatment of Krilium. At the time of sowing these down it was known from sampling of the main plots that reducing the replications to eight would be unlikely to decrease the accuracy of the experiment. As it was intended that these plots should be sampled twice only, their size was reduced to 3 feet square with the intention that sampling take place in the central square foot only. The plan of the layout is shown in Fig. II. It consisted of eight randomized blocks placed again to avoid the influence of tile drains. The situation was similar to that used for the main plots, being about 50 yards away from it. This area had been under crop for an extra year and its previous history was as follows:-

1952-53	Rape
1951-52	Kale
1950-51	Swedes
1949-50	Barley

Prior to the latter date it was included in the same paddock as the land used for the main plots.

The method of preparation of the area for sowing was similar to that employed in the previous year. The seed was sown on the 14th April, 1953 and the conditions of establishment and growth in the early stages were not unlike those obtained from the main plots. The

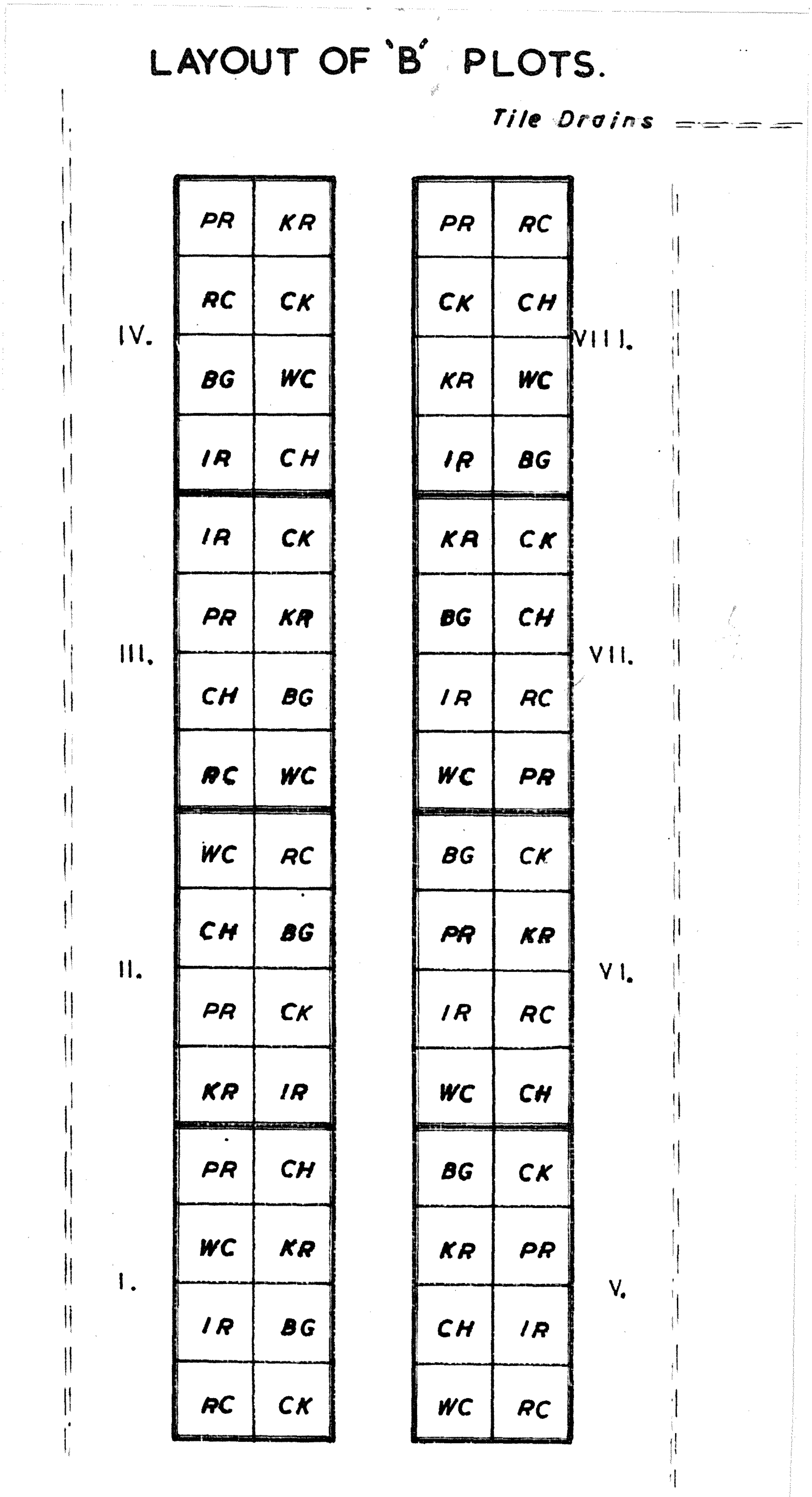

FIGURE II. Diagram showing layout of the "B" plots in relation to existing tile drains. The blocks are indicated by the numbers alongside.

herbage was kept trimmed as previously described but, because of the edge effects in these small plots, it was not weighed.

Krilium was applied to the soil in accordance with the manufacturer's instructions. The soil at the time was damp and the previous cultivation had left it in a crumby state. 37.5 gms. of Krilium was distributed evenly throughout the top six inches of a central cone 18 inches square of each of the replicates by means of a hand fork. After this thorough mixing, each plot was soaked with water.

F. Methods of Structure Determination.

(a) Introduction.

Low (40) has recently surveyed the methods of investigation into the measurement of soil structure. Field studies have been largely descriptive, recording the size and shape of aggregates, the size and shape of the pores and channels, and properties resulting from the aggregates present. Tentative schemes of classification have been recently put forward by Gracinin (22) and Frei (19). However quantitative methods of studying soil structure have been more frequently used, and are mainly confined to the laboratory. Low divides them into three groups:-

(i) Measurement of the size of aggregates by dry sieving. This has been used by Keen (33) and by Russell and Tamhane (71) but suffers from the disadvantage that many soils tend to ball up when used at field moistures and, if used after air drying, are dependent on the pretreatment given.

In this investigation dry sieving following air drying gave no indication of the true position in regard to the stability of soil aggregates. The following are the percentages of dry sieved soil retained on a 3m.m. screen in comparison with the percentage of aggregates retained on a 1.676m.m. sieve after wet sieving (See Appendix V.):-

Treatments	PR	GK	GH	WC	RC	BG
Dry sieved	46.3	42.8	38.1	47.4	44.1	47.8
Wet sieved	85.8	85.6	84.0	81.3	74.4	67.7

If anything, the dry sieving seems to be a measure of the degree of ramification through the soil of the plant roots.

(ii) Measurement of the soil property which is a function of the structure.

These methods are related to the pore space and include such measurements as:-

(1) Infiltration rate of water into soil (45).
(2) Percolation rate (92).
(3) Total pore space (32).
(4) Rate of aeration (101).
(5) Degree of compaction (66).
(6) Ease of cultivation.
(7) Available soil water.

Many of these methods, especially pore space determinations, are widely used in comparing and evaluating soil structure.

(iii) Measurement of the probable stability of a structure. These methods aim to measure the resistance of the soil aggregates to slumping when wetted, and a number of techniques have been evolved:-

(1) Wet-sieving soil aggregates (109).
(2) Subjecting aggregates to the impact of falling water droplets similating the action of rain (42).
(3) Rate of break-down of the air-dry aggregates in wetting (22).
(4) Permeability of a column of air-dry aggregates to water (24).
(5) Extent of the dispersion of the silt and clay fractions in the soil (9).

Of the above, wet sieving techniques have been extensively used because they have produced results which have closely corresponded with known field structural conditions as indicated by ease of seed-bed preparation. The technique was first used by Tuilin (89) in 1928 and amended by Yoder (109) in 1936. Many more recent investigators have used the technique with considerable variation in the details of their methods, depending on soil types and the conditions of the investigations. In addition, the technique is relatively easy to operate and, with careful attention to details of sampling and analytical procedure, good repeatability can be obtained. In view of these advantages, it was decided to use a form of wet sieving as a measure of structure evaluation in this investigation.

The following subsections show how the details of the technique were worked out for the conditions prevailing.

(b) Sampling Equipment.

The sampling area of each plot was restricted to a central core of 8 feet by 1 foot and this was delineated by a framework constructed from No. 8 fencing wire. This left a guard area in each plot one foot wide surrounding the sampling area, and enabled samples to be taken at least this distance from the adjacent treatment. To enable stratified sampling to be easily undertaken, the framework was divided by cross wires into four equal sections, each two feet by one foot in size. (Fig. III). This frame was light in weight and easily handled, and yet sufficiently strong to stand up to frequent use.

Soil samples were taken with the soil sampler illustrated in Fig. IV. This was constructed from a 7 inch length of 2.1 inch internal diameter steel tubing. At one end a layer of bronze approximately 1/10 inch thick was welded inside and extending approximately $\frac{1}{8}$ inch into the tube. This was machined to give an internal diameter of 2 inches. The outside edge was then bevelled off to give a cutting edge of this same diameter. The handle was constructed from $\frac{3}{4}$ inch galvanised water-piping, welded as illustrated.

The smaller diameter of the cutting edge in comparison with the chamber into which the soil sample passes reduces the compression of the sample to a minimum and the effect on its structure is restricted to those surface aggregates that have been in contact with the cutting edge. The smaller the diameter of the sampler the greater would be the effect of cutting and compression. The 2 inch diameter in this sampler was selected as a convenient size for easy handling of the sampling in view of the plot size, and yet sufficiently large to overcome damaging effects to the sample at the time of collecting it. To test this, four pairs of samples were taken from a plot of Chewings fescue, one sample of each pair being taken by the sampler and the other from a block of soil carefully removed with a spade. Aggregate

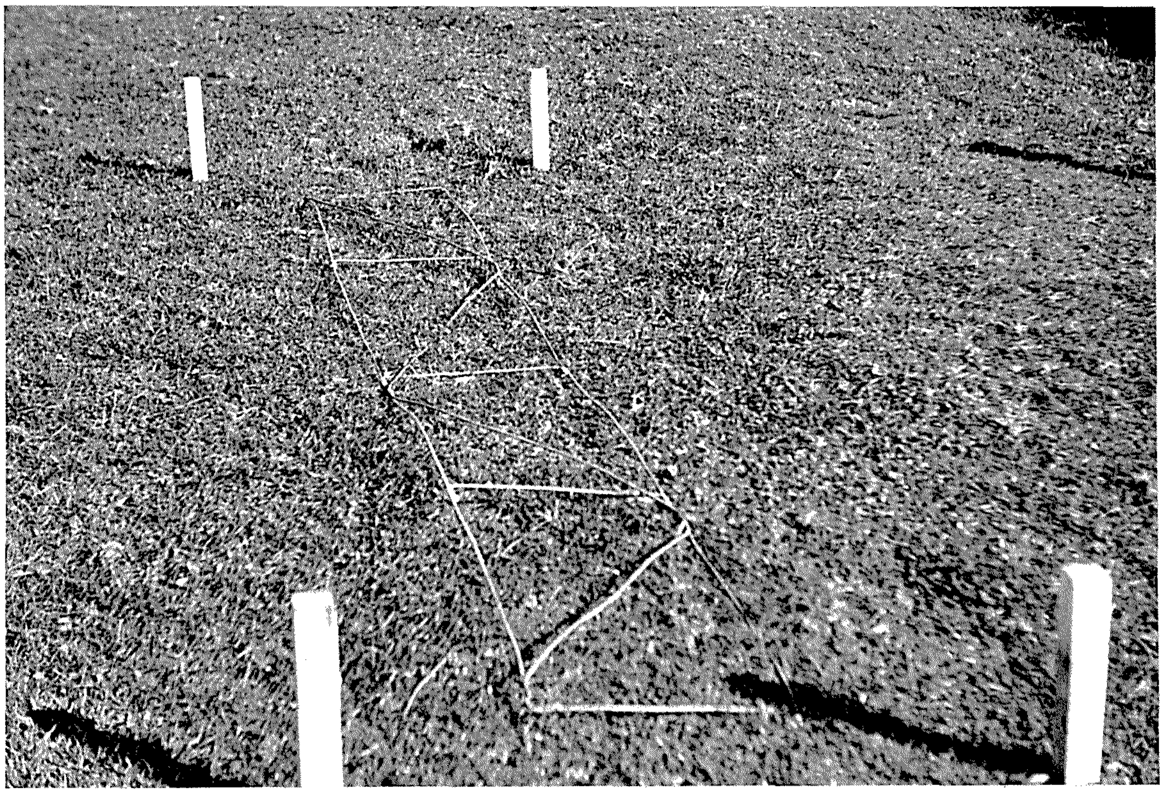

FIGURE III.

Wire framework shown in relation to plot boundaries at sampling time. One sample was taken from each of the four main divisions.

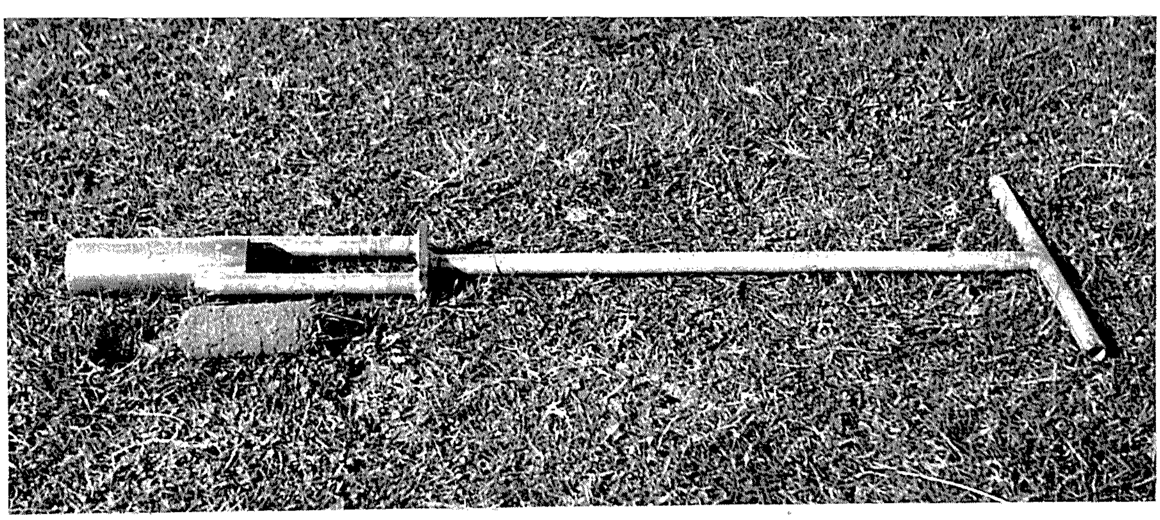

FIGURE IV.

Soil sampler used to take all samples for structure analysis, and to take some samples for root yield determination.

stability measurements on these two sets of samples are given in Table III.

TABLE III. Mean % of Aggregates Retained on 5 MM and 8 MM Sieves.

Sample No.	Sample ex Sampler	Sample ex Spade
1.	60.0	64.3
2.	57.6	57.4
3.	58.5	57.0
4.	57.8	56.1
Total	233.9	234.8
Mean	58.475	58.700
S.D.	1.09	3.76

Very similar results were obtained from each method of sampling and although the number of comparisons is small, they serve to indicate no major variation with the sampling method. The smaller standard deviation obtained from the "sampler" samples would appear to be fortuitous and does not indicate any particular advantage of the sampler in this respect.

Samples for structure determination were taken from series A plots on four occasions:

(i) 20th August, 1952
(ii) 19th December 1952
(iii) 28th April 1953
(iv) 14th December 1953

and on series B plots on:

(i) 11th September 1953
(ii) between 2nd and 21st December 1953.

In taking the samples, the sampling frame was laid out on the plot (Fig. III). On each of the sampling dates four samples were taken from each plot, one from each rectangle of the sampling frame, (83) the position within each rectangle having been predetermined by chance. This was to make certain that the soil sampled at later sampling dates, was not on the site of a previous sample. The actual position for sampling was chosen within the predetermined sample area on a spot where there was an even, dense growth of the species concerned. In the case of the bare ground samples, freedom from weed growth was the only criterion in selecting the site for the sample. Although the coverage of the ground by the grass and clover treatments was as even as could be expected, it was considered that selection within the randomly chosen area would be likely to give less variation from sample to sample. Of the four plugs from each plot, two from one end were bulked into one composite sample, (the X sample), and the two plugs from the other end into another composite sample, (the Y sample). These X and Y samples obtained by this stratified sampling were analysed separately and the results indicated the necessity for such a sampling method. In each of the three occasions that this was done the Y samples were superior in structure stability to the X samples. The mean percentages of oven-dry soil retained after sieving from the two sets of samples were 59.9% for the X samples and 61.7% for the Y samples at four months, 73.5% for the X samples and 74.0% for the Y samples at eight months and 78.4% for the X samples and 82.1% for the Y samples at twelve months. Except for the eight month sample the differences were highly significant. No explanation can be given for this consistently poorer aggregate stability on that half of the plot area adjacent to the tile drains, and time did not permit further investigation into the problem. However, the need for stratified sampling was clearly demonstrated.

After a preliminary drying for two days, the plugs were gently broken up into pieces no larger than a walnut. This was delayed until the soil was dry enough to prevent compression, which would have occurred if breaking up had taken place while the soil was damp, as at the time of sampling. In this way the effect of sample treatment on the structure was kept to a minimum.

(c) Soil Conditions at Sampling.

On each occasion the soil was as near field capacity as possible, the time of sampling being chosen several days after a soaking rain. The following are extracts from the official rainfall figures taken at Grasslands Division, D.S.I.R. prior to each sampling.

A Plot liftings.

Sample	(i)	59 points on 13th and 14th August 1952
"	(ii)	43 points from 14th to 17th December 1952
"	(iii)	31 points from 22nd to 25th April 1953
"	(iv)	77 points on 11th and 12th December 1953.

B Plot liftings.

Sample (i) 80 points from 7th to 10th September 1953.

Moisture content at the time of sampling was measured by the following procedure. After the plug of soil for structure determination had been removed from the plot a triangular prism of soil was taken with a table knife from the side of the hole left after the removal of the sample. One sample from each replicate four inches in depth and weighing about 20 gms was transferred to a bottle and the lid replaced immediately. Samples from the different treatments were kept separate. In the laboratory 50 grams were weighed out from the well mixed aggregate samples of each treatment, dried for 16 hours in the Hearson over at 105°C, (See appendix IV) and weighed after cooling in a dessicator. The results, expressed as the moisture lost per 100 gms. of oven dried soil showed considerable variation and no doubt contributed to some of the differences in structure between lifting periods. The resulting oven-dried soil was then ignited by placing in a cool muffle furnace and raising the temperature to about 800°C for 30 minutes. The loss in weight resulting, expressed in grams per 100 grams of oven-dry soil, is given for the four samplings of the A plots and for one sampling of the B plots in appendix IV. Soil moisture content and loss on ignition was not done for the final sampling of the B plots because each treatment was sampled separately.

(d) Sample Preparation.

Aggregate analyses are most frequently made on air dry samples, because of the variable moisture content of samples taken direct from the field and because of the difficulty of maintaining them in that condition until an analysis can be done. Browning and Milan (8) indicated that the stability of aggregates varied with the moisture content of the soil at time of analysis. Drying of samples decreases the percentage of large aggregates according to Yoder, (109) but this is kept to a minimum by the relatively slow process of air drying. Where comparisons are being made with samples dried under different conditions it is advisable to expose them to the atmosphere for 48 hours before analysis so that they can attain as uniform a moisture content as possible. Low (40) found considerable variation due to humidity differences. Slater (82) however found that soils did not respond uniformly to drying at different rates but the effect was less than that produced by varying field conditions. The practice of air drying was therefore followed in this investigation, but exposure to a uniform humidity was not necessary as the main comparisons were between similarly treated samples.

All the samples were spread out on a table and, when airdry, were placed in sealed bottles on the same day. Samples were checked for moisture content, and no difference between the treatments was found in this respect.

(e) Sub-Sampling.

All methods of structure determinations are empirical in nature and many variations of the wet sieving technique are in use. One of the main difficulties has been to obtain good reproducibility of the results. With this end in view, it has become a common practice in recent years for investigators to screen a restricted size fraction from the air dried sample (7, 49, 71, 73) for aggregate analysis. This reduces the variation caused by the difficulty of obtaining replicates with similar proportions of coarse and fine material as was present in the bulk. Robinson and Page (65) found that 'For greater reproducibility, a size fraction within very narrow limits would be most desirable.' As Bryant (7) points out these lumps selected for analysis are not discrete soil aggregates of a limited size range. Rather, they are small subsamples of the soil mass. Each lump may consist of any proportion of the water stable and water-unstable components of the soil. Russell and Feng (73) found that adequate sampling of an ungraded mixture of aggregate sizes was very difficult. This difficulty of obtaining reproducible results from analysis of the complete soil sample was realised at a very early stage in the present investigation. This was overcome to a great extent by gently sieving the air dry bulk into two fractions, coarse and fine, and then recombining them again into the correct proportions for each replicate (70, 90). This however involved much work and time, and an effort was made to find a more simple method which would give as uniform results. Pouring the soil out into a heap and dividing it into four subsamples with a straight edge ruler gave very poor repeatability. A modification of this, viz, dividing the sample into eight subsamples and then recombining pairs of them in a predetermined manner gave better results, but it was not until a sample divider was obtained on loan from the Seed Testing Station, Department of Agriculture, Palmerston North at a later stage of the investigation, that good reproducibility was obtained. By this time however, the use of a screened sample had been decided upon as a measure of structure stability changes. Table IV gives a measure of the variation in four replicates analysed after being obtained by the three methods mentioned above. The comparison suffers because the methods were not applied to the same bulk. However this should not materially affect the comparison as the only difference was in the depth from which each sample was taken. Later analyses on screened material showed no difference in variability of samples taken from different depths up to six inches.

TABLE IV Aggregate Analysis of four replicates obtained by different methods of subdivision.

Replicate	4"-6" sample divided into four		2"-4" sample divided into 8 and recombined into 4.		0"-2" sample divided by mechanical sampler.	
	% sample retained on 1.676 mm. sieve	% sample retained on .251 mm. sieve	1.676	0.251	1.676	0.251
1	66.32	87.11	57.65	82.65	50.96	81.21
2	69.96	87.36	56.26	81.74	51.52	79.57
3	58.38	82.24	59.33	82.37	51.99	80.43
4	50.42	82.76	56.08	80.26	52.71	81.93
Coefficient of Variation	8.75%	2.85%	2.63%	1.30%	1.43%	1.26%

Martin et al (49) reported that the "use of a segregated soil fraction results in a somewhat different aggregate size distribution curve from that obtained with the entire soil sample." Variation was also experienced in this investigation as illustrated in Table V.

TABLE V. Relative aggregation as determined by three methods.

(BG treatment arbitrarily taken as 100).

0"-2" Sample

Treatment	Screened Sample	Complete Sample	
	1.676 mm. sieve	1.676 mm. sieve	0.251 mm. sieve
BG	100	100	100
RC	109	113	107
WC	115	130	109
CH	118	90	96
CK	118	108	104
PR	118	130	108

2"-4" Sample

Treatment	Screened Sample	Complete Sample	
	1.676 mm. sieve	1.676 mm. sieve	0.251 mm. sieve
BG	100	100	100
RC	109	109	102
WC	114	116	104
CH	125	121	104
CK	124	125	104
PR	123	134	106

4"-6" Sample

Treatment	Screened Sample	Complete Sample	
	1.676 mm. sieve	1.676 mm. sieve	0.251 mm. sieve
BG	100	100	100
RC	108	107	101
WC	115	114	102
CH	123	116	102
CK	124	120	102
PR	123	126	104

(f) Size fraction of Air Dry Soil.

The decision as to what size fraction of the air dry soil sample to use for wet sieving was made on the basis of the experience of Russell and Feng (73), Martin et al (49), Bryant et al (7) where the average size of air dry lumps used was between two mm. and five mm. In this investigation the first analyses were done on the 1-3mm. fraction, but as only very small differences were being obtained between treatments, it was decided to try out the 3-6mm. size fractions. It was found in these first measurements that the latter was more efficient in picking differences between the six treatments. This can be seen in Table VI, columns 1 and 2. Both Woodburn (105) and Low (40) have shown that the size of the air-dry aggregates used influences the amount retained after wet sieving. However, as comparative rather than absolute measurements are normally required, the choice of size fraction to be used will depend on the relative differences that can be measured between treatments and on the fact that more variation is observed with the larger size fractions (see Table VI) due presumably to incomplete slaking during the analysis.

TABLE VI Comparison of Aggregate Analysis of two size fractions screened from soils from six different treatments.

% Aggregates retained after sieving.

Treatment	0"-4" level. Effect of 4 months of treatments.		Treatment	0"-2" level. Effect of 20 months of treatment.		Treatment	4"-6" level. Effect of 20 months of treatment.	
	3-6mm fraction 1.676mm sieve (1)	1-3mm fraction 0.251mm sieve (2)		(3) 3-6mm fraction	(4) 1-3mm fraction		(5) 3-6mm fraction	(6) 1-3mm fraction
Perennial Ryeg.	63.90	75.06	Perennial Rye.	89.08	89.74	Chewing's Fes.	79.66	85.68
Chewing's Fesc.	61.05	73.42	Cocksfoot	87.97	89.52	Cocksfoot	78.67	83.48
White Clover	60.24	72.68	Chewing's Fesc.	87.44	89.36	Perennial Rye.	77.10	83.29
Cocksfoot	59.75	73.51	White Clover	87.01	89.36	Red Clover.	63.41	80.86
Red Clover	58.55	73.13	Red Clover	86.33	87.43	White Clover	59.57	78.34
Bareground	55.51	72.03	Bareground	73.00	82.72	Bareground	60.81	78.03
Diff. for Signif.			Diff. for Sig.			Diff. for Sig.		
5%	2.34	N.S.	5%	2.30	1.42	5%	4.49	2.70
1%	3.19	N.S.	1%	3.07	1.89	1%	5.99	3.61

N.S. indicates not significant

Later analyses done on soils which had been sown down for nearly two years, are shown in Table VI columns 4, 5, 6, and 7. Although the range between treatments was less with the 1-3mm. fraction, this was compensated for by a smaller difference required for significance, giving in the final result no difference in detecting power from the method using the 3-6mm. fraction. However, in comparing the aggregate stability in the two different soil depths, it is seen that there is a much greater range when the 3-6mm. fraction is used. It was decided therefore that the screening of the 3-6mm. fraction was satisfactory for the soil type under consideration. The procedure followed was to force the entire sample through a wire woven sieve having $\frac{1}{4}$ inch square apertures. This was not difficult with a sample which had been gently broken up before becoming air dry. This coarse sieving resulted in removing a big proportion of the roots and, in the case of surface samples the crowns of the grasses and the stolons of the white clover. Occasionally stones would be removed in this coarse screening. The soil passing this was then hand shaken on a round holed 3mm. sieve, in as standardised fashion as possible. It was found that most of the fine material had passed through after twenty sharp sideways movements. The soil particles remaining in the sieve were then transferred to a screw top bottle.

(g) Wetting Samples.

Baver, (4) discussing techniques for wetting dried samples, states that there is no general agreement as to the most satisfactory method. These differ in the speed with which the dry soil is wetted. Immersion in water which rapidly displaces entrapped air and causes shattering when this air pressure is greater than the cohesion of the particles, results in the destruction of large aggregates and clods. The slower wetting obtained by capillarity or with an atomizer gives less destruction, while wetting under vacuum gives the least breakup (70). Even here, however, some destruction takes place due to the swelling effects which occur when a dried clod is wetted. In view of the fact that air drying itself results in artificial conditions, and that the wet-sieving technique merely attempts to compare structural conditions in the soil, it was decided to use the immersion wetting method. Observation on the wetting process showed that entrapped air was not a potent factor in breaking up aggregates the effect on well aggregated soils being almost negligible. It was considered therefore that the immersion wetting method would help to indicate differences between well aggregated soils and those with poor structure. Since commencing this experiment van Bavel (2) has reported on a comprehensive comparison of vacuum-wetted samples with immersed samples. He concluded that vacuum-wetting introduces a large amount of random variation in the results of aggregate analysis and that, adding this consideration to the extra amount of work involved, the use of vacuum-wetting is inadvisable.

(h) Time of Soaking.

There is also no agreement as to the length of time the soil should be soaked before sieving. Russell (70) in 1938 stated that most workers allow the soil at least two hours to wet before subjecting it to aggregate analysis. But the most recent reviews of methods of aggregate analysis by Baver in 1948 (4), Russell in 1949 (74), and van Bavel in 1953 (2) make no comment on the time of soaking and describe methods where sieving commences immediately after wetting. Low (16) at Jealott's Hill and Williams (17) at Hurley, however, soak samples for 30 minutes before sieving. Russell and Feng (9) compared soaking for 3 minutes with 30 minutes and 300 minutes and found that the length of preliminary soaking had no significant effect either on the initial stability or the rate of disintegration of the samples tested. It was decided in the present investigation therefore to limit the preliminary soaking to three minutes in which time the largest of the clods under test were soaked through to the centre.

(i) Size of Working Sample.

The weight of sample used in wet sieving depends on the size of the sieves and the amount of material available. Yoder (109) used 50 gms. on sieves of six inch diameter, Bryant (7) and van Bavel (2) 25 gms. on 5 inch sieves, Russel and Feng (73) 5 gms. on 2 inch sieves. Eight inch sieves were available for this investigation and a start was made with a sample size of fifty grams. It was noticed however, that a very much more vigorous action took place around the outside edge of the sieve than in the centre, and, as sieving progressed, a greater proportion of the larger aggregates were to be found in the centre of the sieve while around the outside edge the aggregates were smaller. As this could conceivably introduce errors into the analyses, ways of overcoming it were considered. Firstly, by keeping the sample away from the outside edge by a liner reducing the effective size of the sieve to one of six inches in diameter, the swirling effect would be avoided. This involved overcoming difficulties of fitting, and it was decided to try instead the effect of a smaller sample placed initially in the centre of the sieve. It was found that when this sample was reduced to 30 gms. it very quickly spread to an even layer over a diameter of about five to six inches once sieving commenced. To see what effect this had on the aggregate stability, four samples each of 10 gms, 30 gms, and 50 gms. were sieved and the results are given in Table VII. The number of samples used was small but the trend was so unmistakably there that further repetition was considered unnecessary.

TABLE VII The effect of sample size on the % of oven-dried Aggregates retained after wet sieving.

Weight of Sample	10 gms.	30 gms.	50 gms.
Replicate A	75.0	63.4	42.8
" B	90.0	80.0	71.6
" C	85.0	72.6	68.4
" D	92.0	90.4	88.2
MEAN	85.5	76.6	67.8

The following points require comment:-

(1) By reducing the sample from 50 gms. to 30 gms. the action of the water appeared more even over the whole sample.

(2) The swirling effect around the edges of the sieve does not appear to be solely, if at all responsible, for the reduction in the aggregates retained. Reducing the sample to 10 gms. has given a very similar difference to that obtained from the previous reduction. The more heavily loaded sieve therefore seems to have caused considerable aggregate abrasion and thus a lower figure for aggregate stability. Just whether this is important or not is still a matter of opinion. Russell and Feng (73) consider the effect of abrasion more important in aggregate stability than the effect of slaking. Bryant et al. (7) incline the other way. Nijhawan and Olmstead (57) suggest that any abrasion that is done should occur by shaking the sample in an end-over-end shaker prior to sorting the particles by a short period of wet sieving. In this way all the material in the sample is exposed to substantially the same treatment. In was thought advisable however, in this investigation to reduce the sample size from 50 gms. to 30 gms. to avoid any possible swirling action on the outside.

(j) Pre-shaking.

At a later stage the effect of shaking the sample in an end-over-end shaker for ten turns was tested against no shaking. Unlike Wilson, Gish and Browning (104) who found that the soils of poorest aggregation were least damaged by shaking, results of this investigation showed a more pronounced effect of shaking on the soils of poorest aggregate stability, Fig. V, and Table VIII shows the reduction in aggregates greater than 1.676 mm. as a result of shaking.

TABLE VIII % of oven-dried aggregates greater than 1.676m.m. retained after 5 minutes sieving.

Treatment	CH	PR	CK	WC	RC	BG
No preshaking	90.1	90.0	89.5	86.3	83.3	78.8
Shaken 10 times	83.2	82.8	81.7	75.7	71.6	65.2
Diff. due to shaking	6.9	7.2	7.8	10.6	11.7	13.6

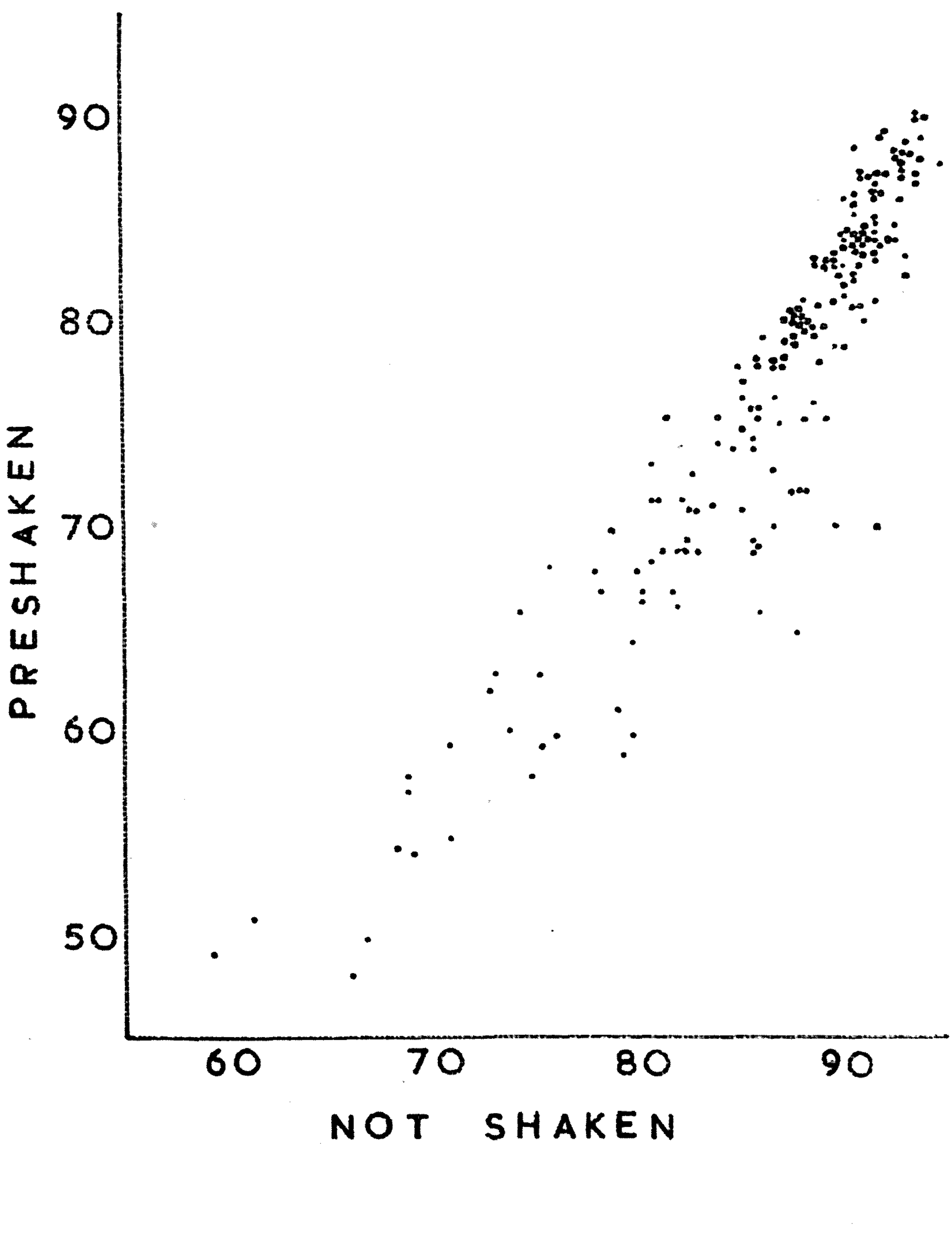

FIGURE V.

Graph showing the relationship between aggregate stabilities of duplicates measured with and without preshaking. Both scales give the percentage soil retained on a 1.676 mm. sieve.

Wilson, Gish and Browning used the whole soil sample as compared with a screened selection of 3-6 mm. clods in this case. However, their bluegrass (Poa pratensis) sod appears to have produced an easily abraded aggregate compared with those of the grasses and clovers used in this investigation. The relatively little effect of shaking on their "continuous corn" sample was probably due to the fact that it had almost reached the minimum possible level of aggregation even without abrasion.

Fig. V shows the relation between the percentage of aggregates >1.676 mm. when preshaken 10 times and the percentage when not shaken. The decreasing steepness of the curve at the lower levels of aggregate stability indicates that the effect of shaking is greater here. The two methods place the treatments in the same relative order as seen in Table VIII. The increasing difference obtained on the samples of poor stability by shaking did not result in increased detection of differences between the treatments. This is shown in Table IX.

TABLE IX. Analysis of variance of preshaken and unshaken samples.

	Not shaken (% of aggregates >1.676 mm. converted to angles)				Shaken (% of aggregates >1.676 mm.)			
Source of Variation	Degree of freedom	Mean sq.	F	Result	Degree of freedom	Mean sq.	F	Result
Blocks	9	11.66			9	25.93		
Treatments	5	131.77	23.2	**	5	530.52	41.8	**
Residual	45	5.68			45	12.70		

** indicates significant at the 1% level of probability.

Table of Means.

Treatment	Not Shaken (Converted to Angles)	Shaken
PR	71.6	82.8
CK	71.1	81.8
CH	71.7	83.2
WC	68.4	75.7
RC	66.0	71.6
BG	62.7	65.2

TABLE IX (Contd.)

Not Shaken	Shaken
For significance at the 5%(1%) level, difference must exceed 2.15 (2.88)	For significance at the 5%(1%) level, difference must exceed 3.22 (4.30)
Coefficient of Variation = 3.47	Coefficient of Variation = 4.64

The above results indicated that with the soil under consideration no advantage in accuracy or detection power could be obtained from the increased work involved in preshaking the samples.

(k) Wet-sieving Apparatus.

Most investigators have retained the main features of the original Yoder (109) wet-sieving apparatus. Variations involving such features as the number of samples that can be analysed at one time, the number of sieves used to divide up any one sample, the diameter of the sieves used, and whether the sieves are lifted clear of the water at each upward motion or not, are numerous. But usually the sieves are raised and lowered in water about 30 times per minute, moving through a vertical distance of approximately $1\frac{1}{2}$ inches.

The apparatus used in this investigation is illustrated in Fig. VI. It is based partly on one developed by A.J. Low at Jealott's Hill with the exception that both sets of sieves are raised and lowered at the same time. It was made in the College workshops and consists of a 1/6 H.P. electric motor connected by a belt and pulleys to an Alger reduction gear box which reduces the revolutions to 32 per minute. The gear box is connected by an offset shaft to a rigid frame moving in brass slots. This is offset sufficiently to give a $1\frac{1}{2}$ inch movement up and down in the frame. Each of the two arms of the frame is connected by three pieces of No. 8 fencing wire to a galvanised iron strip fashioned to hold an 8 inch sieve. The ends of the strip can be held together by a bolt and thumbscrew or more quickly by a wire staple. The apparatus is bolted onto a wooden frame with a sponge rubber base. When in operation, the apparatus is placed on a bench with the sieve holders containing the sieves hanging over the edge and dipping into two 12 inch diameter cylinders

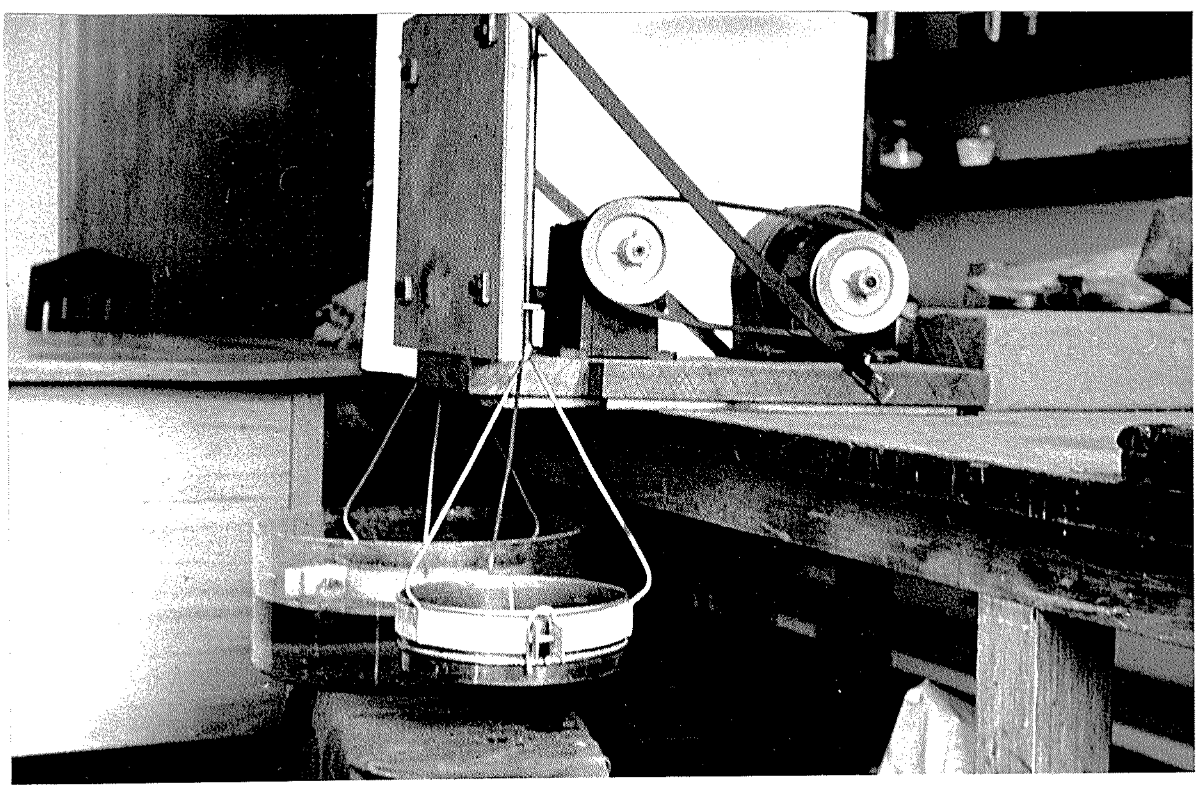

FIGURE VI.

Wet-sieving apparatus used for aggregate stability determinations. The glass water container has been removed from the nearer sieve to show the method of attachment.

of water. One or two sieves can be fitted in each sieve holder for each determination. Low (40) has shown a reduction in stability of aggregates with increasing water temperature used in sieving and Singh (81) has described a water bath used to give constant temperature. It was considered that these precautions were rendered unnecessary in this investigation because all treatments analysed from any one block were sieved in the same water on the same day. The sieves were set up so that the top one was just covered with water when in the highest position. It was then immersed to its lowest position. The weighed sample of soil was tipped onto the middle of the immersed sieve and soaked for 3 minutes before sieving commenced. Five minutes sieving or 160 strokes was generally used for a simple separation with a single 1.676 mm. sieve but where unscreened samples were analysed on two sieves, (a 1.676 mm. as above together with a 0.25 mm. sieve) 5 minutes was insufficient to enable a separation to be made, and it was extended to 960 strokes or 30 minutes sieving. Singh (81) has emphasised the need for adjusting the rate of sieving and the number of immersions to the soil under test, but this appeared to be more important where sieves of small aperture were being used. In this experiment care was taken to see that there was no pasty deposit left on the sieves, and that the sample remaining after sieving was granular in structure.

To gain some knowledge of the effect of sieving for different periods of time, a series of analyses was done on soil samples from the A plots in December 1952. Sieving took place for 3, 5, 15 and 30 minutes on 50 gram samples drawn from each treatment. Soil was available from seven blocks. Details of the aggregate stability measured under these conditions will be found in Appendix V. In Table X a summary of these results is presented.

TABLE X Effect of length of sieving time on the relative stability of structure of soils from plots of pure sowings of grasses and clovers. (% oven-dried soil retained after analyses on a 1.676 mm. sieve.)

Treatment / Time of sieving	PR	CK	CH	WC	RC	BG
3 minutes	80.3	83.8	87.6	79.9	76.7	66.7
5 minutes	76.7	76.4	79.7	74.7	70.3	58.7
15 minutes	64.4	65.1	66.6	62.7	58.5	45.7
30 minutes	56.0	57.5	59.1	53.3	51.2	39.1

Fig. VII shows the same results in graphical form and it can be seen that there is a steady decline with all treatments with increased time of sieving. But the range and order of placing the different treatments varies only slightly. From the appearance of the graph it appears that a considerable increase in time of sieving would be necessary before a constant weight of soil would be left. There appears to be no advantage in seeking such information in an investigation such as this where relative figures are required rather than absolute ones. The saving in time resulting from sieving for 5 minutes instead of 30 minutes or more has resulted in a much more complete range of replicates being analysed, without any apparent loss in accuracy.

After the required time of sieving had elapsed, the machine was stopped, the immersed end raised manually and propped up to bring the sieves out of the water. The sieves were then removed and the soil washed off with a gentle stream of tap water into an 8 inch basin. After settling for some minutes the clear water was decanted off and the soil gently washed into a 3 inch crucible. After further settling the amount of water was reduced by further decanting and the crucible placed in a Hearson oven at 105°C. for 16 hours. All samples were then placed in dessicators until cool, when they were weighed. Weighings of soil were made on an Eta triple beam balance

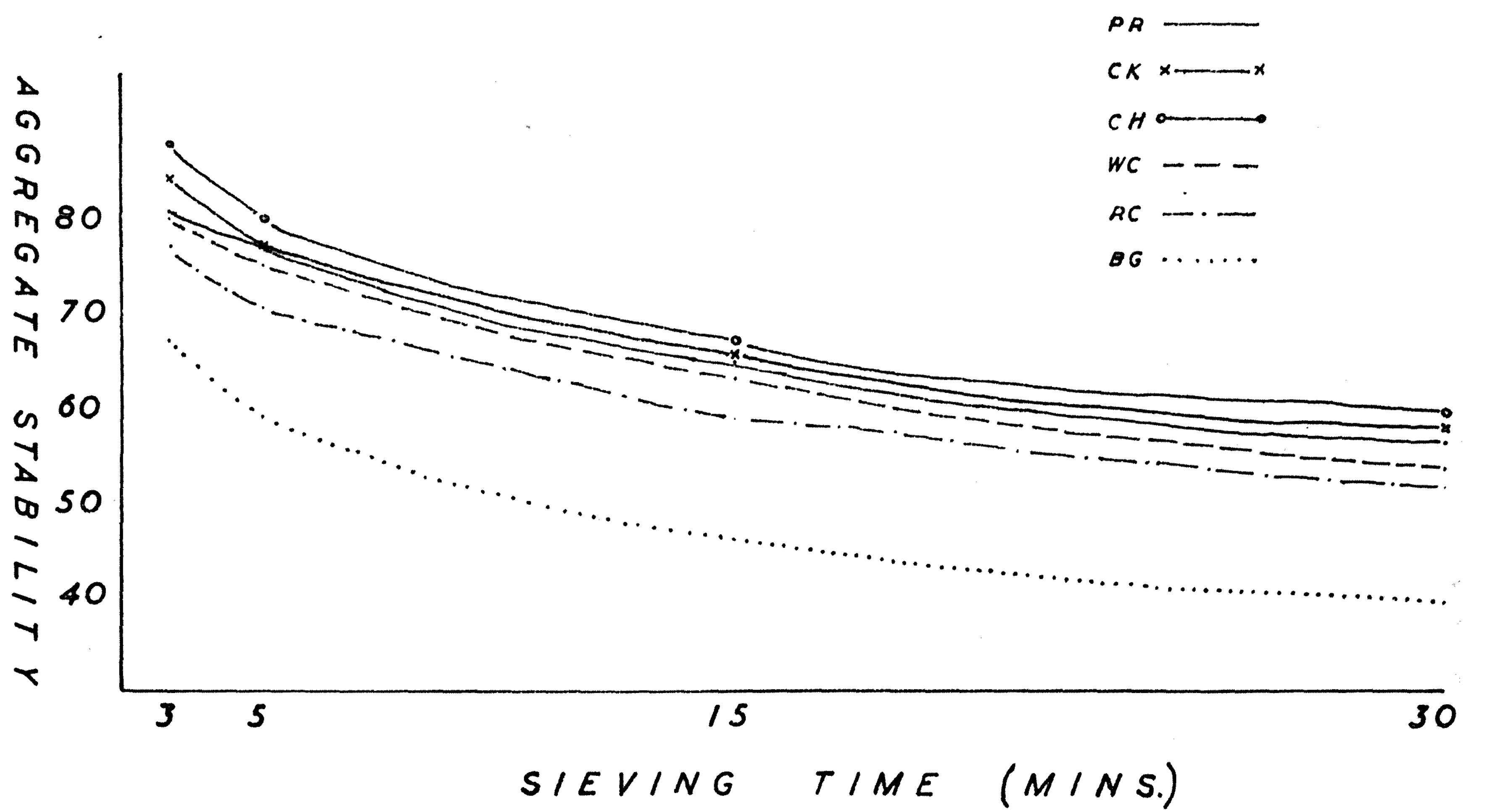

FIGURE VII. Graph showing the effect of different times of sieving on the percentage of soil retained on a 1.676 mm. sieve.

accurate to 0.1 gm. Determination of the primary particles by dispersion, sieving, oven-drying and weighing was not done because of the small proportion of such particles greater in size than 1.676 mm., the aperture size of the most commonly used sieve. (see Table II). Further, comparisons were being made between samples taken from a very restricted area and one that was relatively even in soil texture. It was considered that no improvement in accuracy would be obtained from this additional information.

(1) Expression of Results.

There are many ways in which the results of wet sieving analyses can be expressed. Where aggregate size distribution has been determined, the percentage by weight of each size class is obtained. Many workers then proceed to develop a single number to compare treatments or soils. Schaller F.W. and Stockinger K.R. (77) have recently surveyed the indices used for this purpose and have compared some of them. They found that the use of a single size separate such as the percent aggregates >2 mm. or >1 mm. could be as reliable as the mean weight diameter (2) or geometric mean (37) for expressing aggregation. These two latter indices which take into account the proportion of aggregates in each size class involve much more laboratory work than the one size fraction which can be determined on one sieve. Some single figure indices such as "degree of aggregation" (60, 89), "aggregation index" (64) and "dispersion ratio" (52) involve a determination of the size distribution of aggregates both before and after dispersion. This would be worth while if additional information were gained by it, but where comparisons are being made between different treatments on the same soil, no further information is obtained by dispersing the sample and resieving, or in determining the primary particles present on each sieve (49, 73). Browning et al (6) for instance for Gilpin soils found the dispersion ratio to be highly correlated with the percentage of aggregates >0.25 mm.

In view of these findings and also because of the consistently even moisture content of all the air-dry samples from any one lifting, results in this investigation are reported as the weight in gms. of oven dried soil retained on either a 1.676 mm. or a 0.251 mm. sieve per 100 gms. of air dried soil.

(m) General.

To test the effectiveness of the technique, a number of check sievings on other than the plot soils were done during the course of the investigation.

1. Samples drawn from an old pasture of at least 50 years standing were compared with samples taken from the plot area and from nearby cultivated soils. The percentages of oven dried soil retained on a 1.676 mm. sieve from the different treatments sampled in December 1952 were as follows:-

Old pasture	91.0	(Mean of four determinations)
2-Year old ryegrass	77.1	(Mean of three determinations)
CH (8 months from sowing)	79.6	
CK " "	77.8	
PR " "	77.0	
WC " "	74.7	
RC " "	72.7	
BG " "	60.8	

A similar sampling in April 1953 gave the following results:-

	Old Pasture	Cultivated Land	PR	CK	CH	WC	RC
0"-2"	92.3	36.8	89.4	88.6	88.7	86.3	82.5
2"-4"	92.7	32.6	87.0	87.4	88.0	80.0	75.9
4"-6"	91.9	34.3	85.5	85.7	85.8	78.8	74.3

2. The Krilium treatment in the B plots was markedly superior to all other treatments both four and eight months after sowing, as measured by percentage of oven dried soil retained on a 1.676 mm. sieve.

	Krilium	Mean of Other Treatment
4 months after sowing	78.1	46.2
8 months after sowing	83.8	66.4

This is in line with the results of Krilium treated soils elsewhere, the structure of which has been assessed by other techniques (23).

3. The technique was tested on a series of pot soils obtained from Grasslands Division, D.S.I.R.. In these the effect of the additions of dung on the subsequent stability of the soil aggregates was recorded in the following results:-

	Following Clover	Following Grass
Dunged soil	70.4	80.1
Untreated soil	45.4	39.0

Improved structure following addition of organic matter such as dung has been shown by many investigators (47, 85) and the present technique has clearly evaluated these soils satisfactorily.

Further samples from pots which had received dung with and without earth worm additions gave the following percentages of oven dried soil retained on a 1.676 mm. sieve.

Untreated soil	3.8
Worms only	1.9
Dung only	80.6
Dung and worms	82.5

In this case, while the effect of dung has been clearly demonstrated, worm activity has produced no effect on stability. This is in line with Dutt's results (14). He found little effect on potted soils but considerable improvement in stability of worm casts obtained from the field.

G. Method of Root Determinations

(a) Introduction.

The object of the study of root development in this investigation was to obtain a measure of those variables in sub aerial growth which were likely to influence the physical condition of the soil in which they were growing. The soil could conceivably be affected by (a) the weight of root in the different soil depths. (b) The number and degree of ramification of the roots and (c) the relative rapidity of breakdown of the roots present. The great variation that occurs in root growth depending on the soil type, management of the top growth, recent climatic conditions and fertility made it necessary to endeavour to obtain the necessary information from the plots on which structure determinations had been done, and to obtain that information from samples taken as close as possible to the structure sampling positions and at the same time.

Many methods have been used in root development studies, the choice generally being made to suit particular circumstances. With pasture work, root development can be studied either in single plants, the results from which have to be interpreted with reserve, or under sward conditions with consequent sampling and recording in the field, a method likely to give results more closely allied to practice. Single plants are frequently grown in special soil mixtures in pots from which they can be easily removed (28). Samples taken from pastures whether in plots or on paddock scale may be more difficult to separate. It is known that variations in environmental conditions produce great differences in root development. Such factors as fertility, moisture, frequency of defoliation and competition are important in this respect, and to avoid these effects on the plots, uniformity was achieved by eliminating stock with their irregular fertility pattern, and defoliating the plants with a mower whenever the height reached eight to ten inches. In this way moderately dense growth of the required species was obtained without serious weed infestation.

(b) Equipment and Methods.

The same plots were used for root samplings as for structure determinations. Two main methods were used.

(1) For the first part of the experiment the method was the same as that used in many previous root studies by Jacques (27). The equipment consisted of a sampler made from angle iron and having internal dimensions of 2 9/16 in. by 2 9/16 in. by 13 in. (28). This is driven into the ground with a maul to the desired depth and after being levered out of the soil, the sample is extracted by unscrewing the side bolts which hold the two halves of the sampler together. Wooden sample boxes of the same dimensions as the sampler and capable of being divided into two, longitudinally, are used to remove the sample from the sampler. One half of the box is placed over the sample as it lies in the opened sampler, the whole is inverted and the sample thus transferred to the sample box without any disturbance. The sample in the box can then be taken from the field to the laboratory for root washing.

(2) For the final root samplings, the above sampler was replaced by the tubular sampler devised for the structure sampling. This was done for the following reasons.

(i) In the previous samples, the variability, particularly in root weights, but also in structure stability within a plot was very great, and affected very materially the establishment of any relationship between these two factors. It was decided therefore to try and obtain a better measure of the effect, if any, of root weight on structure by using the 0"-2" and the 4"-6" layers of the soil samples for structure determinations and the 2"-4" layer for root development studies. Only the tubular sampler could be used for this purpose.

(ii) It was found from earlier structure analyses that there was a highly significant regression of structure stability of the 2 - 4 inch layer on structure stability of the top 2 inch layer.

(See Table XI.) It was considered therefore that a very good estimate could be made of the structure position in the second 2-inch section, and that this could then be related to root data actually obtained from it.

TABLE XI. Relationship of structure in top 2-inch layer with that in the 2 - 4 inch layer. Regression Analysis (20 month sample).

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Regression of 2-4 in. structure on 0-2 in. structure.	1	197.92	27.15	4.04	7.19	**
Residual	48	7.29				

** indicates significance at the 1% level of probability.

(iii) The reduction in size of sample from an area of 44.89 sq. cm. in the case of the Jacques sampler to 20.15 sq. cm. in the case of the tubular sampler was found to result in reduced laboratory separations, without increasing the variability of the sampling. Table XII shows the comparative coefficients of variation for the two methods. Ten samples were taken in each case.

TABLE XII. Coefficient of Variation of root weights in the 2-4 in. soil depth for both the Jacques sampler and the tubular sampler.

Treatment	CK	CH	PR	WC	RC
Jacques sampler April, 1953	13.2	16.7	13.4	36.4	59.9
Tubular sampler Dec., 1953	21.3	15.6	22.6	28.3	42.6

Whatever method of sampling was used, all treatments were sampled on any sampling day. Usually this was kept at one sample per treatment so that they could be analysed within a few days of sampling, thus preventing them from drying out or making new growth before analysis.

The samples were brought into the laboratory for analysis which followed very closely the methods used by Jacques (30). The sample was cut carefully into 2 inch layers which were washed separately on a nylon sieve. This was of plain-weave mesh with 21 holes to the inch and appeared to act as efficiently as a horse hair sieve in retaining roots while allowing soil particles to pass through. By carefully breaking up the soil in the sieve while the latter was resting in a pan of water and following this with gentle agitation of the sieve in the water, the sample was considerably reduced without the loss of root material. Decantation onto a rubber baffle and a certain amount of cleaning of the sample with forceps completed the separation. The hand work was much increased where surface samples were being analysed because seeds and undecayed leaves were difficult to separate from roots.

The cleaned root sample was squeezed as dry as possible between blotting-paper and when all the samples in the lifting had been completed, usually within two days, they were placed in weighing bottles in a drying oven and dried at 105°C for 16 hours. After drying they were kept in a dessicator until cool when they were weighed on a Sartorius balance, the weights being recorded to the nearest milligram.

H. Compilation of Results

(a) Structure Determinations.

The oven dried soil retained on the sieves after the prescribed period of sieving was converted to a percentage of the original air dried sample and these figures are set out in Appendix V. Where the bulk of these percentage figures reached a level of 80 or more, the whole series was transformed to angles as prescribed by Snedecor (83). The treatment means were found from these tables and an analysis of variance done in the normal way (83), when a simple comparison of treatment effects was being made.

When samples from two or three depths were being compared in addition to the species effects, a variation of the normal split-plot analysis of variance was used as suggested by Leonard and Clark (38). This was necessary because of the impossibility of randomizing the depth samplings within any one treatment plot.

The difference required for significance between the means of subplots within any one main treatment and vice versa was calculated from the formula given by Cochran and Cox (10).

(b) Root Determinations.

The yields of oven-dried roots for each of the four liftings are recorded in Appendix VI. Mean yields and root numbers were calculated and the significance of any differences occurring was determined as mentioned above. No analysis was done on tiller numbers as they were recorded merely to indicate the density of the plant population in each plot at that stage of growth.

(c) Missing Plots.

On several occasions soil samples were inadvertently mixed or lost through being spilt. Usually, however, enough of the sample remained to supply a duplicate. Where this could not be arranged a calculated replacement was used. This was obtained by using the following formula (106).

$$x = \frac{tT + bB - S}{(t-1)(b-1)}$$

where t = Number of treatments

b = Number of blocks

T = Sum of items with same treatment as the missing item

B = Sum of items in the same block as the missing item

S = Sum of all observed items

Wherever it was necessary to use this formula the total degrees of freedom for each analysis of variance involving such an item was reduced by one for each calculated missing value.

SECTION IV

RESULTS

A. Soil Structure.

(a) Preliminary

To find out what short term differences, if any, could be expected in structure stability of a soil under different pasture swards, a series of spade samples were taken on the 11th February 1952 from a grass species and strain demonstration block sown two years previously on the Field Husbandry Area. These grasses had been sown with white clover as a companion plant, but dominantly grass sites were chosen for sampling. Duplicate 50 gm. samples of the unscreened soil were wet sieved, one on an 8 I.M.M. sieve and one on a 16 I.M.M. sieve. The mean of these two was used to indicate the structural condition of the soils. An adjacent area which had been under cultivation for three years was sampled at the same time. Results of these analyses are given in Table XIII.

TABLE XIII Percentage stable aggregates, in soils from two year old pasture strains plots., and cultivated land.

Plot Sampled	Sample No.	Percentage Aggregate Stability	Mean for each Treatment.
Perennial Ryegrass	(a)	69.9	
	(b)	71.1	
	(c)	69.7	
	(d)	69.6	70.1
Cocksfoot	(a)	75.9	
	(b)	71.9	
	(c)	70.2	
	(d)	69.5	
	(e)	69.8	
	(f)	68.6	71.0
Chewings Fescue	(a)	51.7	
	(b)	44.7	
	(c)	60.3	
	(d)	59.0	53.9
Cultivated Land	(a)	33.0	
	(b)	38.3	
	(c)	31.3	34.1

Although these results could not be statistically analysed, there was sufficient difference between them to indicate that plots sown down with different species would be likely to produce different effects on the soil structure within a short space of time.

These samples taken from the top four inches of soil showed quite marked differences in appearance. Although no apparent difference could be detected by wet sieving between cocksfoot and ryegrass samples, the former appeared to have a greater crumb formation while the latter was more inclined to be cloddy. The Chewings fescue plot gave a soil sample which appeared to have been divided into relatively small particles by a mass of grass roots. It was difficult to separate the soil from the roots near the crown of this grass. The soil from the cultivated ground was almost devoid of roots and slumped or slaked much more rapidly than the other samples when placed in water.

Following this preliminary investigation, the replicated A plots were sown down and sampled for the first time four months after sowing.

(b) Four Month Sample.

A Plots. These were sampled to a depth of four inches on August 20th, 1952.

Table XIV gives the percentage of the 1-3 mm. screened sample retained on a 0.251 mm. sieve. (4 determinations from each of 5 replicates), and the percentage of the 3-6 mm. screened sample retained on a 1.676 mm. sieve (4 determinations from each of 10 replicates).

TABLE XIV Structure stability 4 months after sowing.
Analysis of Variance.

Source of Variation	1-3 mm. sample						3-6 mm. sample					
	d.f	Mean Square	F	F Required 5%	F Required 1%	Result	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Blocks	4	13.5					9	217.6				
Treatments	5	20.7	2.21	2.56	3.76	N.S	5	253.7	11.7	2.43	3.46	**
Residual	19H	9.36					45	21.6				
Coefficient of Variation	4.16						7.6					

H Reduced by one due to loss of one sample

N.S. indicates not significant.

** indicates significant at the 1% level of probability

Treatment Means.

Treatment	1-3 mm. sample Mean of 20 determinations	3-6 mm. sample Mean of 40 determinations
PR	75.0	64.1
CK	73.5	60.5
CH	73.4	62.5
WC	72.7	60.6
RC	73.1	60.4
BG	72.0	56.6
Detectable differences	—	5% 2.09 1% 2.80

B Plots. Sampled to a depth of four inches in two sections 0"-2" and 2"-4", on 11th September, 1953.

Table XV gives the percentage of the 3-6 mm. screened sample retained on a 1.676 mm. sieve. (Single determinations from each of 8 replications.)

TABLE XV. Structure stability 4 months after sowing.
Analysis of Variance.

Source of Variation	0" - 2"		2" - 4"		0" - 4"	
	Mean Square	F	Mean Square	F	Mean Square	F
Blocks	193.8		234.6		211.1	
Treatments	1403.5	64.3**	1112.7	22.68**	1257.9	51.22**
Residual	21.82		49.06		24.56	
Coefficient of Variation		9.3%		17.1%		10.9%

** Indicates significance at the 1% level of probability.

Treatment Means (8 determinations at each depth)

Treatment	0"-2"	2"-4"	0"-4"
PR	47.9	39.2	43.6
CK	44.2	34.0	39.1
CH	53.2	44.1	48.7
WC	50.0	36.8	43.4
RC	46.2	37.9	42.1
BG	30.6	26.6	28.6
KR	70.1	67.0	72.5
IT	50.2	42.2	46.2
Detectable differences 5% (1%)	4.70 (6.27)	7.03 (9.38)	4.98 (6.65)

Discussion of Tables XIV and XV.

1. Except for cocksfoot in Table XV the grasses have tended to be superior to the clovers in building up structure stability.

2. The bare ground treatment has been inferior in each case, significantly so where the 3-6 mm. screened sample was used.

3. The B plots were sown on a soil more deficient in structure than the A plots.

4. Krilium has raised the aggregate stability to a higher level than any other treatment despite being used on the B plot area.

5. The effects have not completely corresponded in the two years, but there are no contradictory results.

6. Improvement in stability was more rapid in the top two inches (Table XV) than in the next two inches, the effect being least in the BG plot.

(c) Eight Month Sample.

A Plots. These were sampled to a depth of 4 inches in one section on December 19th, 1952. Table XVI gives the percentage of 3-6 mm. screened sample retained on a 1.676 mm. sieve. (Duplicate samples from each of 10 replicates)

TABLE XVI. Structure stability 8 months after sowing.
Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5% (1%)	Result
Blocks	9	86.60			
Treatments	5	924.54	52.86	2.43(3.46)	**
Residual	45	17.49			
Total	59				

Coefficient of Variation = 5.7%

** significant at the 1% level of probability.

Treatment Means (20 determinations of each treatment)

Treatment	Percentage Stability
PR	76.98
CK	77.75
CH	79.57
WC	74.70
RC	72.66
BG	60.76

Detectable differences at the 5% (1%) level are 2.64 (3.52)

B Plots. These were sampled to a depth of six inches in three 2 inch thicknesses on 14th December, 1953.

Table XVII gives the analysis of variance of the percentage of the 3-6 mm. screened sample retained on a 1.676 mm. sieve. (Single determinations from each of eight replicates.)

TABLE XVII Structure stability 8 months after sowing.
Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Blocks	7	315.7				
Treatment	7	1187.3	19.07	2.21	3.04	**
Residual (a)	49	62.3				
Total	63					
Blocks	7	315.7				
Depths	2	2201.7	93.17	3.80	6.70	**
Residual (b)	13 X	23.6				
Total	22					
Plots of Treatments	63					
Deviation of depth plots from blocks	15					
Treatment X Depth	14	79.0	2.30	1.80	2.29	**
Residual (c)	98	34.38				
Total	190					

X Reduced one degree of freedom for missing Plot.
Coefficient of Variation = 11.6%
** indicates significance at the 1% level of probability.

Treatment & Depth Means (Eight determinations at each depth)

Depth	PR	CK	CH	WC	RC	BG	KR	IT	Depth Means
0"-2"	72.56	73.79	75.24	74.63	72.79	68.25	88.70	75.84	75.22
2"-4"	59.71	64.26	69.11	64.00	65.88	57.11	87.91	62.84	66.35
4"-6"	57.84	62.20	71.63	60.23	67.59	55.93	74.69	63.04	64.14
Treatment Means	63.37	66.75	71.99	66.28	68.75	60.43	83.77	67.24	68.57

Treatments: For significance at the 5% (1%) level, difference must exceed 4.60 (6.17).

Depths: For significance at the 5% (1%) level, difference must exceed 1.86 (2.59).

Treatment Means at any one Depth: For significance at the 5% (1%) level, difference must exceed 6.29 (8.35).

Depth Means for any one Treatment: For significance at the 5% (1%) level, difference must exceed 5.68 (7.53)

Discussion of Tables XVI and XVII.

1. In the A plots the grasses have again been superior to the clovers, while in the next season (the B plots) there is no difference.

2. Bare ground samples have been significantly inferior in both seasons and in nine comparisons out of ten at the 1% level of probability.

3. The Chewings fescue treatment has tended to be most effective of the grasses in each season, almost significantly superior in the A plots, while in the B plots there was a highly significant difference between Chewings fescue and perennial ryegrass.

4. The effect of Krilium has been markedly superior to any of the other treatments.

5. Improvement in stability has been better nearer the surface.

6. In most cases the treatments have reacted similarly at the three depths, but Red Clover and Chewings Fescue are exceptions and have shown less deterioration with depth than the other treatments.

(d) Twelve Month Samples.

A Plots. Ten replicates were sampled to a depth of 6 inches in three 2 inch sections on April 28th, 1953. After airdrying the 3-6 mm. samples were wet sieved on a 1.676 mm. sieve. The following is an analysis of variance for structure stability. As many of these percentages were over 80%, they were transformed to angles according to Snedecor (83) and analysed as such.

TABLE XVIII. Structure stability 12 months after sowing. Analysis of variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	(1%)	Result
Blocks	9	76.34	4.45	2.10	2.82	**
Treatments	5	889.84	51.92	2.43	3.45	**
Residual (a)	45	17.14				
Total	59					
Blocks	9	76.34				
Depths	2	348.50	58.87	3.55	6.01	**
Residual (b)	18	5.92				
Total	29					
Plots of treatments	59					
Deviation of depth plots from blocks	20					
Treatment X depth	10	16.00	7.55	1.94	2.53	**
Residual (c)	90	2.12				
Total	179					

Coefficient of Variation = 6.16%

** indicates significance at the 1% level of probability.

Treatment & Depth Means (20 determinations at each depth)

Depth / Treatment	0"-2"	2"-4"	4"-6"	Mean
PR	74.43	71.34	68.77	71.51
CK	73.08	71.93	69.77	71.59
CH	71.97	72.17	70.27	71.47
WC	70.87	65.97	64.64	67.16
RC	67.14	61.26	60.20	62.87
BG	61.47	57.57	56.86	58.63
Mean	69.83	66.71	65.09	67.21

Treatments: For significance at the 5% (1%) level, difference must exceed 2.15 (2.88).

Depths: For significance at the 5% (1%) level, difference must exceed 0.92 (1.27).

Treatment Means at any one Depth: For significance at the 5% (1%) level, difference must exceed 2.20 (2.92).

Depth Means for any one Treatment: For significance at the 5% (1%) level, difference must exceed 1.68 (2.28).

Discussion of Table XVIII.

1. The grass plots are highly significantly superior in stability of structure to the clover and bare ground plots. But there is no difference between the three grass species themselves.

2. The clover plots are highly significantly superior in stability of structure to the bareground plot, and white clover is superior to red clover to the same degree.

3. A highly significant difference between the stability of structure at different depths exists, stability decreasing with depth.

4. The highly significant interaction between depth and treatment is due to the results found with -

(i) Cocksfoot, and Chewings fescue which showed no better stability in the top two inches than in the 2"-4" level. It will be noted from Section III (d) of Appendix VI that the dry sieving of Chewings fescue gave a much lower percentage of 3-6 mm. sized granules in the top two inches than did perennial ryegrass and to a lesser extent cocksfoot. The intensity of rooting of Chewings fescue has apparently divided the soil into a greater proportion of small sized granules. It was noted that the sieving process resulted in some of these being retained in the 3-6 mm. group through attachment to larger granules by roots and that in the wet sieving process these became detached and passed through the 1.676 mm. sieve. To a lesser extent this happened with cocksfoot. Despite this, the stability of these soils was not significantly less than that on which ryegrass had grown. In the lower depths the presence of very fine particles was not noted.

(ii) White clover, red clover and bare ground which showed no improvement in structure in the 2"-4" sample over the 4"-6" sample.

(iii) In the 0"-2" sample perennial ryegrass was superior to Chewings fescue.

(e) Twenty Month Samples.

A Plots. Ten replicates were sampled to a depth of 6 inches in three 2 inch sections on 14th December, 1953. After airdrying the 3-6 mm. screened samples were wet sieved on a 1.676 mm. sieve. Table XIX gives the analysis of variance for structure stability.

TABLE XIX Structure stability 20 months after sowing. Analysis of variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Blocks	9	32.67	1.96	2.10	2.84	N.S
Treatments	5	384.94	23.09	2.43	3.46	**
Residual (a)	45	16.67				
Total	59					
Blocks	9	32.67	5.15			
Depths	2	708.32	111.72	3.55	6.01	**
Residual (b)	18	6.34				
Total	29					
Plots of treatments	59					
Deviation of depth plots from blocks	20					
Treatment X depth	10	29.16	8.65	1.94	2.53	**
Residual (c)	90	3.37				
Total	179					

Coefficient of Variation = 5.93%

** indicates significance at the 1% level of probability.

N.S. indicates difference not significant.

Treatment & Depth Means (10 determinations at each depth)

Treatment \ Depth	0"-2"	2"-4"	4"-6"	Mean
PR	74.05	71.59	69.45	71.70
CK	74.08	71.35	68.37	71.27
CH	73.58	71.62	70.21	71.80
WG	73.54	68.23	64.19	68.65
RC	72.64	66.70	60.22	66.52
BG	66.02	62.24	60.28	62.85
Mean	72.32	68.62	65.45	68.80

Treatments: For significance at the 5% (1%) level, difference must exceed 2.11 (2.82).

Depths: For significance at the 5% (1%) level, difference must exceed 0.97 (1.32)

Treatment Means at any one Depth: For significance at the 5% (1%) level, difference must exceed 2.50 (3.32).

Depth means for any one Treatment: For significance at the 5% (1%) level, difference must exceed 1.90 (2.56).

Discussion of Table XIX.

1. The analysis shows very similar results to those of the previous sampling time despite an elapse of eight months.

2. The grasses again, while significantly superior to the other plots show no difference between themselves.

3. The clovers are again highly significantly superior to bare ground but white clover is superior to red clover at the 5% level of significance.

4. The same highly significant difference between stability at different depths still persists. In this case Chewings fescue at the 0"-2" level just gains significant superiority over the 2"-4" level.

5. The highly significant interaction between depth and treatment is due to -

(i) In Chewings fescue there was no significant difference between the structure in the two lower soil levels.

(ii) In the 0"-2" sample the grasses were not superior to the two clovers.

(iii) In the 0"-2" and 2"-4" levels white clover was not superior to red clover.

(iv) In the 4"-6" level red clover was not superior to bare ground.

B. Root Determinations.

Root samples were taken to correspond with those used for structure stability analysis. However as it was not expected that significant differences in the latter would be obtained in less than a year from sowing of the plots, no root samples were taken for the first two sampling periods of the A plots. Information on root development at this stage of growth was obtained later from the B plots.

A general comparison of root development of the 20 month period is shown in Table XX and Fig. VIII, the 2"-4" section being used for this because it was sampled most frequently.

TABLE XX Root yields (in mgms. D.M.) for the 2"-4" soil level corrected to a standard sample size of 44.89 sq. cms.

Time from sowing. \ Treatment	WC	RC	CH	CK	IR	PR
4 months	138.5	167.0	187.4	212.3	238.8	261.6
8 "	-	-	347.8	315.7	304.5	341.0
12 "	163.0	503.5	414.7	279.6	-	345.8
20 "	216.3	724.9	636.2	301.8	-	400.6

(a) Four Months Sample.

The B plots were sampled with the Jacques sampler to a depth of four inches between 21st August and 5th October, one core being taken from each sown treatment of one block each sampling day. The four inch sample was divided into two sections of two inches each. The following information was obtained from the separation of each of these samples and can be found in Appendix VI.

1. weight of oven dry roots.
2. number of roots attached to tillers.
3. number of tillers.
4. number of worms present.

1. Weight of Oven Dry Roots.

Table XXI gives the yield of oven dry roots from the two sampling

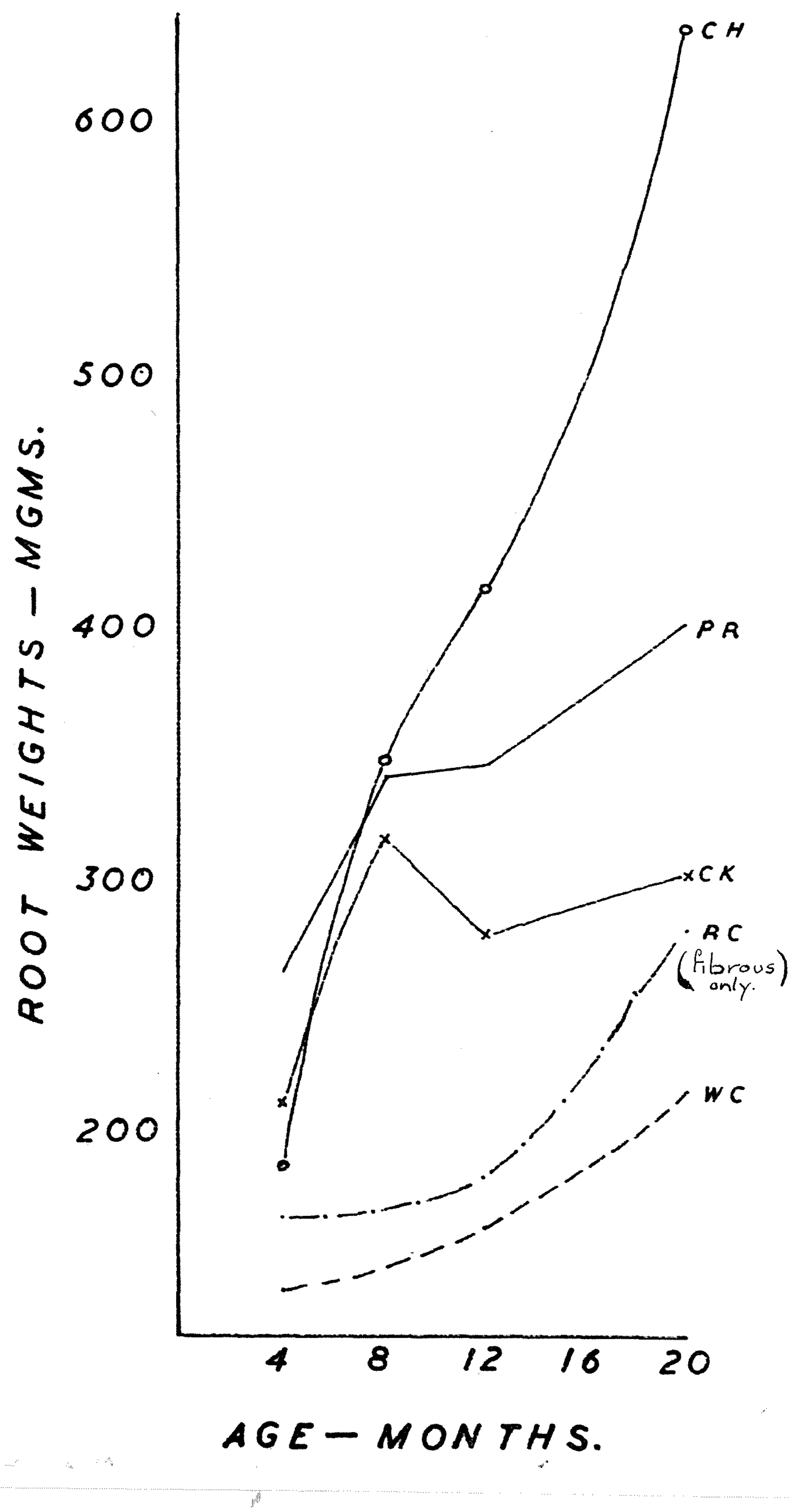

FIGURE VIII.

Graph showing the charges in live root yields in the 2"-4" depth during the experimental period of twenty months. Weights refer to a sample area of 44.89 sq. cms.

depths.

TABLE XXI Root weight (mgms. dry matter per 44.89 sq. cms.) four months after sowing. Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Blocks	7	58621				
Treatments	5	59119	13.49	2.48	3.59	**
Residual (a)	35	4384				
Total	47					
Blocks	7					
Depth	1	2360341	188.16	5.59	12.25	**
Residual (b)	7	12544				
Total	15					
Plots of Treatments	47					
Deviation of depth plots from blocks	8					
Treatment X Depth	5	4212	1.74	2.48	3.59	N.S.
Residual (c)	35	2420				
Total	95					

Coefficient of Variation = 18.5%

** indicates significance at the 1% level of probability

N.S. indicates not significant.

Treatment & Depth Means (mgms. D.M. per 44.89 sq. cm.)

Depth / Treatment	0"–2" Section.	2"–4" Section	Treatment Means
PR	609.0	261.6	435.3
CK	527.0	212.3	369.6
CH	470.6	187.4	329.0
RC (Complete)	469.3	167.0	318.2
WC	416.5	138.5	277.5
IT	594.8	238.8	416.8
Depth Means	514.4	200.9	357.7

Treatments: For significance at the 5% (1%) level, difference must exceed 47.4 (63.7).

Treatment Means at any one Depth: For significance at the 5% (1%) level, difference must exceed 60.5 (81.2).

Depth Means for any one Treatment: For significance at the 5% (1%) level, difference must exceed 91.6 (126.0).

Discussion of Table XXI.

1. The grasses, in particular the ryegrasses, have yielded a greater amount of root material than the clovers. Chewings fescue, being relatively slow to establish, would be expected at this stage to be less productive of root than ryegrass and to a lesser extent cocksfoot.

2. White clover, being slower to develop than red clover is also less productive of roots.

3. The lack of significance between PR and CK, and CK and RC in the 2"-4" depth and between CK and RC in the 0"-2" depth accounts for the almost significant reaction between depth and treatment.

2. Number of Crown Roots.

Table XXII gives the number of crown roots cut from the base of the tillers in the sample area of 44.89 sq. cms.

TABLE XXII. Crown Roots numbers four months after sowing. Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Blocks	7	12289				
Treatments	5	210720	31.01	2.49	3.60	**
Residual	35	6794.5				
Total	47					

Coefficient of Variation = 37%

** indicates significance at the 1% level of probability.

Comparison of Species.

CK	PR	CH	IR	WC	RC
438.1	288.8	280.8	279.1	45.1	15.6

For significance at the 5% (1%) level, difference must exceed 83.6 (112.2)

Discussion of Table XXII.

Cocksfoot at this age has many more crown roots than the other grasses. They are very fine and permeate the soil intensely in the top two inch section while Chewings fescue has a dense surface root system which appears to be achieved by more branching of the roots below the crown. The ryegrasses have much thicker roots, the white roots being more prominent and there are fewer fine roots. The clovers at this age have only one main root per plant and the whole root system is dependent on this tap root and is much sparser than that of the grasses, although individual roots are thicker.

3. Number of Tillers.

A picture of the density of plant cover at the time of sampling is gained from the tiller numbers per unit area which are given below:-

PR	72
CK	44
CH	184
WC	49
RC	36
IR	42

4. Number of Worms.

No differences in worm population were found between treatments.

(b) Eight Month Sample.

The B plots were sampled with the Tubular Sampler to a depth of six inches between the 2nd and 21st December, 1953, the four grass species only being used. The samples were divided into three two inch sections the centre one being used for root study. Because these samples were primarily to find any connection between roots and structure within a species and not for comparisons of structure effects or root development between species, the eight replicates of a species were sampled each sampling day, as opposed to the sampling of all treatments in any one block as previously done.

Table XXIII sets out the root weights in the 2"-4" soil section.

TABLE XXIII. Root weight (mgms. D.M. per 20.15 sq. cms.) in 2"-4" soil section eight months after sowing.
Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	1%	Result
Blocks Treatments Residual	7 3 21	632 699 521	1.34	3.07	4.87	N.S.
Total	31					

Coefficient of Variation = 15.3%
N.S. indicates not significant.

Comparison of Treatments. Mgm. D.M. per 20.15 sq. cm.

PR	CK	CH	IT
155.0	143.5	158.1	138.4

Discussion of Table XXIII.

(1) Although no significant differences occur between these four grass species there is a definite trend towards greater increase. in root growth in Chewings fescue in comparison with the other species. This is further shown in Table XVIII and Fig. VII in which root yield at the four sampling periods is converted to a comparable sample size. At the earlier sampling Chewings fescue was significantly poorer than the other three grasses.

(2) A disadvantage of using the 2"-4" section is apparent in that differences in root weight between species is less at this level than nearer the surface. Consequently significant differences may have been obtained had the 0"-2" section been used for root separation. Alternatively further replications would have increased the chance of getting significant differences.

(c) Twelve Month Sample.

The A plots were sampled with the Jacques sampler to a depth of six inches between 25th March, 1953 and 20th May, 1953. One sample was taken from each plot and divided into three 2 inch sections. At this stage of growth it was impossible to make an accurate count of root numbers. In all samples the roots were washed and freed of soil and organic matter, dried and weighed. Results are tabulated in Table XXIV.

TABLE XXIV. Root weights (mgms. D.M. per 44.89 sq. cms.) in three successive two inch soil depths twelve months after sowing. Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Blocks	9	24924				
Treatments	4	1181163	45.98	2.63	3.89	**
Residual (a)	36	25688				
Total	49					
Blocks	9					
Depth	2	7170487	585.92	3.55	6.01	**
Residual (b)	18	12238				
Total	29					
Plots of treatments	49					
Deviation of depth plots from blocks	20					
Treatment X depth	8	361363	22.15	2.07	2.77	**
Residual (c)	72	16315				
Total	149					

Coefficient of Variation = 34.8%

** indicates significance at the 1% level of probability.

Treatment & Depth Means (mgms. D.M. per 44.89 sq. cms.)

Treatment	0"–2" Section.	2"–4" Section.	4"–6" Section.	Treatment Means
CH	1411.7	414.7	317.8	714.7
PR	1134.7	345.8	241.9	574.1
CK	977.6	279.6	205.9	487.7
WC	549.9	163.0	115.4	276.1
RC (Fibrous Only)	403.8	183.0	156.9	247.9

Treatments: For significance at the 5% (1%) level, difference must exceed 83.96 (112.61)

Depths: For significance at the 5% (1%) level, difference must exceed 46.50 (63.69).

Treatment Means at any one Depth: For significance at the 5% (1%) level, difference must exceed 166.03 (220.80).

Depth Means for any one Treatment: For significance at the 5% (1%) level, difference must exceed 110.60 (148.18).

Discussion of Table XXIV.

1. Significant differences in root yield occur between all the species except that the two clovers can not be separated. Chewings fescue has shown definite superiority, a trend indicated in the previous lifting.

2. Root yield has decreased at a highly significant rate with depth. All species show this but red clover does so to a less degree than the remaining four species.

3. The highly significant interaction is accounted for mainly by the fact that there are significant differences between the grasses in the top soil level but not in the other two depths. Much more even root yields are obtained below the top two inches where variation is very marked between species.

4. The red clover yields are in terms of fibrous roots. The main tap root was excluded from the analysis because although it was only a single root, it weighed approximately twice that of all the fibrous roots in the sample.

(d) Twenty Month Sample.

The A plots were sampled with the tubular sampler between the 16th November, 1953 and 30th November, 1953. As in the case of the eight month samples, the six inch depth was divided into three sections, the 2"-4" section being used for root determinations and the remainder for structure. Results are given in Table XXV.

TABLE XXV Root weights (mgms. D.M. per 20.15 sq. cms.) in the 2"-4" soil section twenty months after sowing.
Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	1%	Result
Blocks	9	2908				
Treatments	5	75826	30.08	2.43	3.46	**
Residual	45	2521				
Total	59					

Coefficient of Variation = 35.2%
** indicates significance at the 1% level of probability.

Comparison of Species: D.M. per 20.15 sq. cm.

CH	PR	CK	RC	WC	BG
289.2	182.1	137.2	116.5	98.3	32.3

For significance at the 5% (1%) level, difference must exceed 45.21 (60.39).

Discussion of Table XXV.

1. Because it was not possible to keep down weed growth on the bare ground plots entirely, it was decided to sample them for root growth at this stage in order to have some knowledge of its extent in view of the gradual improvement in soil structure in these plots since sowing time. The weeds present were predominantly sheep sorrel (Rumex acetosella) with a little Boa annua, and the yields recorded include the creeping underground stems of the former which added greater bulk to the sample than a similar length of root. There is therefore not as much ramification of roots in these plots as the weights might appear to indicate.

2. The root weights of the grasses remain greater than those of the clovers. Chewings fescue has opened up a greater gap on the others; cocksfoot shows comparatively little change over the previous twelve month period, its superiority over the clovers not reaching significance.

3. The red clover root yields do not include the main tap root of plants in the sample. Fibrous root yields of red and white clovers show no significant difference, a position similar to that of the previous sampling.

C. Summary of Results

1. In each of the four samplings made for the determination of structure stability, the soil from the grass plots has been consistently superior. In most cases this superiority was highly significant. No consistent differences were recorded between the grasses. There was a tendency for the ryegrass soil to be superior in the top two inch layer, but it showed greater deterioration in the lower levels than the soil from cocksfoot and Chewings fescue plots.

2. The soils from the clover and bare ground plots were consistently placed in the order of white clover, red clover, bare ground. Significance was achieved in the majority of these comparisons between structure stabilities.

3. Root development as indicated by the weight of fibrous root tissue present at different stages of growth, was more intense in the grass species than in the clovers.

4. The percentage decline in root weight with depth was very consistent for all species. Although the clovers tended to have a greater proportion of their roots in the top two inches in the early stages, by the time the plants were a year old, all species had practically the same proportion of their living roots in the top two inches. The percentage of the 0"-6" root weight actually present in the 0"-2" section varied for any one species by no more than 0.57% from the mean percentage which was 66.15%.

SECTION V.

ROOT DECOMPOSITION

A. INTRODUCTION

In Section IV three measureable root characteristics were mentioned as possible factors influencing physical conditions in the soil in which the roots are growing. The variations in root weight and root numbers between species were dealt with there. Root decomposition will be dealt with in this section.

It is generally accepted that decomposing organic matter in the soil has a favourable effect on aggregate formation (85). Thus the effect of plant roots in changing the soil structure may be due to the residues left when the roots die in addition to (a) the actual binding effect that the roots may have on the soil particles and/or (b) the compression of the soil into more or less stable crumbs by the growing roots as they ramify through the soil (72).

The decomposition of root material commences very early in the life of plants, but is on a relatively small scale being almost solely confined to the root hairs. However, within the first few months of the life of a grass plant the seminal roots begin to deteriorate, and they make some contribution to the supply of organic matter to the soil (107). Also, under pasture conditions, there is a considerable mortality of young grass and clover plants in the establishment period extending up to twelve months from sowing, and the roots of these plants represent a considerable but as yet unmeasured proportion of the additions to the soil organic matter in that time. Even where grass roots have not died, there is usually a gradual deterioration with age and this involves the sloughing off of the cortex (29) while the stele still remains operative.

In view of this more or less continuous supply of food in the form of plant roots to the soil organisms which takes place under pasture, it was decided to measure the rapidity of breakdown in soil of the roots of the different species under consideration, and also to see whether the rate of this breakdown could be related to the stability of the soil structure.

B. THE EXPERIMENT

(a) General.

In this section, soil taken from an area adjacent to the plots already mentioned was used in pots. This soil had been under cultivation for over four years and was low in stability of structure in comparison with neighbouring pasture areas. The method used was to add equal weights of roots of the different species in the soil to pots and thoroughly mix the two. Water was added to approximately field capacity and the pots were placed in an unheated glasshouse. Samples were taken at intervals, and the Warburg Apparatus was used to determine the rate of decomposition of organic matter in them. At rather longer intervals, the pots were sampled for structure stability which was determined by means of wet sieving.

(b) Material and Equipment.

The soil was obtained from an intensely cultivated area and, after air-drying, it was passed through a 3 mm. round holed sieve, practically all of it going through quite easily. It was then sieved on a 1 mm. round holed sieve and the material retained on this sieve was used for potting. From previous experience, it was known that such material containing particles of a very narrow size-range would provide much more consistent sub-samples than could be obtained from the complete soil bulk. It was important to have a standard soil sample on which to apply the treatments.

200 gms. of this air-dried soil was mixed with 3 gms. of oven-dried roots obtained from the root separations described in Section IV. Where sufficient root material was available, pots containing soil with 6 gms. of roots were made up also. In order to get an intimate and even mixture between the roots and the soil, the roots were first put through a hammer mill. The mixture was of sufficient size to fill a plastic pot of $3\frac{1}{2}$ inch top diameter and 2 inch bottom diameter to within $\frac{1}{2}$ in. of the top. Duplicate pots of each treatment

were put down. 65 gms. of tap water was gently added to each pot, this being sufficient to bring the moisture content of the samples up to about 37%, this being near the field capacity of the soil. To reduce evaporation to a minimum a polythene plastic cover was fitted over the top of each pot and secured by an elastic band. Thus without reducing aeration conditions it was possible to maintain an even moisture content in the pots, only one watering being necessary in three months, and that only to the extent of 3 gms. per pot.

The following treatments were applied in duplicate:-

1. No added roots.
2. White clover roots from plots sown 4 months.
3. White clover roots from plots sown 12 months.
4. Red clover roots from plots sown 4 months.
5. Red clover roots from plots sown 12 months (fibrous roots only)
6. Red clover roots from plots sown 12 months (tap root only)
7. Chewings fescue roots from plots sown 4 months.
8. Chewings fescue roots from plots sown 12 months.
9. Chewings fescue roots from plots sown 12 months. (6 gms. per pot.)
10. Cocksfoot roots from plots sown 4 months.
11. Cocksfoot roots from plots sown 12 months.
12. Perennial ryegrass roots from plots sown 4 months.
13. Perennial ryegrass roots from plots sown 12 months.
14. Perennial ryegrass roots from plots sown 12 months. (6 gms. per pot.)
15. Italian ryegrass roots from plots sown 4 months.

The pots available were not all the same colour and so as to avoid any effects of light they were placed inside 4 inch clay pots into which they fitted snugly. Light was excluded from the surface by placing a tin tray over the top of the grouped pots. Duplicate randomized blocks each consisting of 15 pots were set out on a glass house shelf where ventilation and temperature were considered uniform. The layout is shown in Fig. IX.

In addition to the above, single pots of the following treatments were included also.

1. Red clover roots from plots sown 12 months (tap root only, 6 gms. per pot.)
2. Cocksfoot roots from plots sown 12 months (6 gms. per pot).

LAYOUT OF POTS

BLOCK A

13	10	4
5	11	1
9	7	6
12	15	3
14	8	2

BLOCK B

5	1	6
7	8	3
9	14	13
12	15	4
11	10	2

FIGURE IX.

Diagram showing layout of the pot experiment in the glasshouse.
(see page 74 for key to pot numbers.)

Minimum day temperatures varied from 44°F to 62°F and maximum day temperatures varied from 73°F to 103°F during the period that the pots were in the glasshouse.

The normal method of measuring the rate of decomposition of soil organic matter has been by recording the evolution of carbon dioxide (68, 93) or the oxygen up take of that soil (68). In view of the fact that a Warburg apparatus was available in the Botany Department of the College, it was decided to use it for this purpose. The apparatus is of standard design (13) and was made in the College workshop. It contains twelve manometers. Each treatment was done in triplicate in order to obtain satisfactory accuracy, so that only four treatments could be compared at any one run of the apparatus.

(c) Method.

1. Root Decomposition Rates.

The pots were filled with the soil-root mixture and watered on the 10th November 1953. Twenty-four hours later sampling commenced. As all pots could not be sampled at the same time it was necessary to have a control treatment in each run of the apparatus. This left three other treatments which could be included. The apparatus was available for only two days in succession which limited the treatments that could be tested to six. It was decided therefore to make a comparison of the grasses the main object, and to concentrate on those pots to which the 12 month old roots had been added. This root material was very free from the roots of other grass species, weeds, etc. In addition it was possible to include some of the clover pots to give a general idea of how they behaved in comparison with the grasses.

The pots to be sampled were brought into the laboratory just before sampling. On the first day 5 gms. of the wet soil was taken from each pot. This was weighed to the nearest milligram on the Sartorius balance in a weighing dish with the lid on. After the first sampling the amount of soil was reduced to 3 gms. as this amount made the manometer readings simpler. The transfer of this soil to the flask was arranged by plugging up the well with a stopper on a thin shaft, and fitting a paper funnel over the inlet to avoid any loss of the soil particles in the transfer. The soil was distributed evenly around the well. Into the latter a small filter paper strip was placed and three micro litres of 20% potassium hydroxide were carefully added with a pipette. This was to absorb the carbon dioxide produced. Readings on the manometer scale thus indicate the amount of oxygen absorbed by the soil, and this respiration rate indicates the activity of soil micro organisms and thus the decomposition of the organic matter present.

The temperature of the water bath was maintained at 30°c. No continual shaking of the apparatus was practiced. Shaking has been shown to be unnecessary by Webley (99) and Rovira (67) where soil samples are used in the Warburg apparatus.

Readings of the manometer scales were made every half-hour, but an analysis of the results was made on the average hourly absorption of oxygen, this being obtained from the final reading, generally six hours after the start. After this final reading, the soil was carefully washed from each of the flasks into small porcelain drying dishes and dried for 16 hours in a drying oven at 105°F. These were then cooled in a dessicator and the oven-dried soil was weighed to the nearest milligram. Oxygen absorption per gm. of oven dried soil was used as the basis of comparison between treatments.

The pots were sampled four times over a period of two months viz:-

1. 11th and 12th November, 1953.
2. 18th and 19th November, 1953.
3. 3rd and 4th December, 1953.
4. 5th January, 1954.

2. Stability of Structure Measurements.

Thirty days after the soil in the pots had been moistened it was removed from the pots of Block A and spread out to air-dry. This was on the 10th December, 1953. On the 24th December when dry it was put into airtight bottles. Four series of samples were taken from these bottles over the next month and wet sieved to measure the stability of the soil aggregates. 25 gms. was the sample size used, this being soaked for 3 minutes and sieved for 5 minutes on a 0.251 mm. sieve.

Forty days later the soil from Block B was spread to air-dry. This was on the 19th January, 1954. This was bottled on the 9th February, 1954 and analysed for stability of aggregates on the two following days in the same manner as Block A.

C. Results

(a) Root Decomposition.

In Fig. X the rates of absorption of oxygen over the four sampling periods are graphed. Tables XXVI to XXIX give the results of the individual samplings and the significance of the differences measured at each sampling.

TABLE XXVI. Rate of oxygen absorption in micro litres per gm. of oven-dried soil one day after moisture added.
Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Species	5	261.8863	8.57	2.81	4.34	**
Residual	17	30.5450				
Total	22					

Coefficient of Variation = 39.8%

** indicates significance at the 1% level of probability.

Comparison of Species: microlitres of O_2 absorbed per gm. of dry soil.

Control	PR	CK	CH	RC (New)	WC (New)
7.14	9.61	9.71	14.40	24.74	27.30

For significance at the 5% (1%) level, difference must exceed 9.52 (13.07)

TABLE XXVII Rate of oxygen absorption in micro litres per gm. of oven-dried soil eight days after moisture added.
Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Species	6	49.643	9.94	2.70	4.10	**
Residual	17	4.993				
Total	23					

Coefficient of Variation = 32.2%

** indicates significance at the 1% level of probability.

Comparison of Species: microlitres of O_2 absorbed per gm. of dry soil.

Control	CK	PR	CH	WC (old)	RC (old)	WC (new)
2.60	4.54	5.39	6.89	8.93	9.91	14.51

For significance at the 5% (1%) level, difference must exceed 3.84 (5.27)

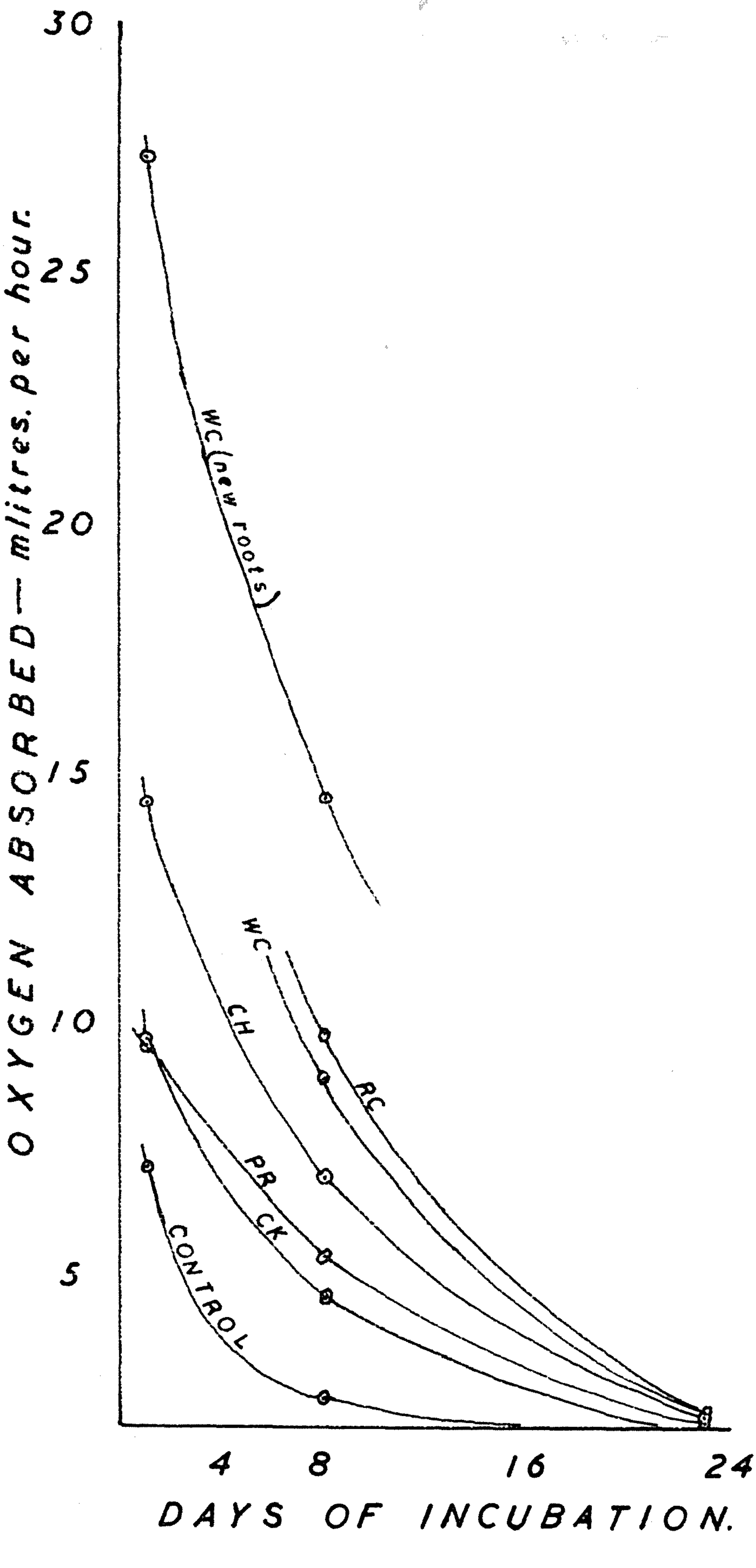

FIGURE X.

Graph showing changes in oxygen absorption rate during the first part of the incubation period. (The base line represents 2 mlitres. of oxygen absorbed per hour).

TABLE XXVIII Rate of oxygen absorption in microlitres per gm. of oven-dried soil 23 days after moisture added. Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Species	7	.4341	3.52	2.66	4.03	*
Residual	16	.1232				
Total	23					

Coefficient of Variation = 16.0%

* indicates significance at the 5% level of probability.

Comparison of species: microlitres of O_2 absorbed per gm. of dry soil.

Control	CK	PR(6gms)	PR	CH	WC(old)	RC(old)	CH(6 gms)
1.81	1.88	2.04	2.08	2.18	2.26	2.29	3.04

For significance at the 5% level, difference must exceed 0.608.

TABLE XXIX Rate of oxygen absorption in microlitres per gm. of oven-dried soil 56 days after moisture added. Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Species	3	1.2517	12.31	4.07	7.59	**
Residual	8	0.1017				
Total	11					

Coefficient of Variation = 15.1%

** indicates significance at the 1% level of probability.

Comparison of species: microlitres of O_2 absorbed per gm. of dry soil

Control	CH	PR	CK
1.18	2.23	2.36	2.67

For significance at the 5% (1%) level, difference must exceed 0.60 (0.87)

Discussion of Tables XXVI to XXIX.

1. Oxygen absorption has been consistently lower in the untreated soil at all stages of the experiment.

2. Soils treated with clover roots have been better, weight for weight, than the grasses in oxygen absorption.

3. Rates of absorption are high initially and taper off rapidly

followed by a period of slow deterioration until presumably a constant rate of absorption is reached. This is in line with the findings of Rovira (68).

4. Soils with double quantities of added roots have tended to be greater in oxygen absorption than those with the normal addition.

5. In the case of added clover roots, the young roots have tended to induce a more rapid oxygen absorption than the older roots.

(b) Structure Determinations.

Fig. XI shows a histogram of the percentage stability of aggregates of the potted soils 30 and 70 days after the addition of the roots and the moistening of the soil.

Table XXX and XXXI give the results of each sampling.

TABLE XXX % stability of soil aggregates 30 days after addition of grass and clover roots.
Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required		Result
				5%	1%	
Replications	3	162.91				
Treatment	15	75.82	13.2	1.89	2.47	**
Residual	45	5.75				
Total	63					

Coefficient of Variation = 3.5%

** indicates significance at the 1% level of probability.

Comparison of Treatments: % aggregates retained on a 0.251 mm. sieve.

Treatment	Aggregate Stability
Control (a)	61.2
Control (b)	63.4
PR (old)	64.6
CH (old)	65.9
CK (old)	66.6
CH (young roots)	66.9
RC (old: fibrous roots)	67.0
PR (old: 6 gms.)	68.3
CK (young roots)	68.8
IT (young roots)	70.4
PR (young roots)	70.4
WC (young roots)	70.5
WC (old)	71.3
CH (old: 6 gms.)	72.1
RC (young roots)	76.1
RC (old, tap root)	77.8

For significance at the 5% (1%) level, difference must exceed 3.42 (4.56).

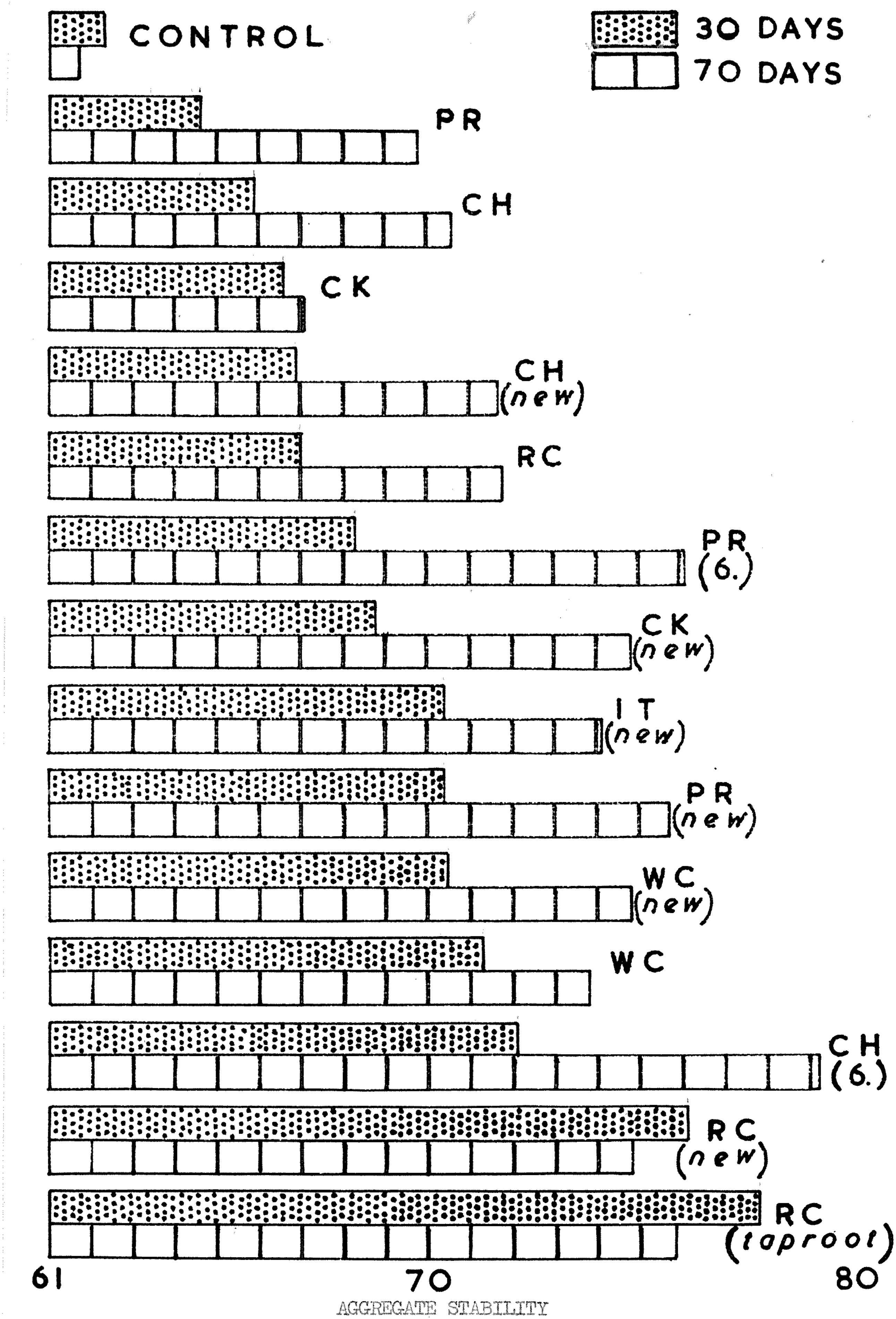

FIGURE XI. Histogram of aggregate stability of soils taken from pots (a) 30 days after the addition of water and roots and (b) 70 days after. Aggregate stability was measured by the percentage aggregates retained on a 0.25 mm. sieve. (NEW refers to four months old roots. Remaining roots are from 12 months old plots.)

TABLE XXXI. % stability of soil aggregates 70 days after addition of grass and clover roots.
Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required		Result
				5%	1%	
Replications	3	3.47				
Treatments	16	124.99	18.94	1.88	2.44	**
Residual	48	6.60				
Total	67					

Coefficient of Variation = 3.5%

** indicates significance at the 1% level of probability.

Comparison of Treatments: % aggregates retained on a 0.251 mm. sieve

Treatment	Aggregate Stability
Control	61.7
CK (old)	67.1
PR (old)	69.8
CH (old)	70.6
CH (young roots)	71.7
RC (old)	71.8
WC (old)	73.8
IT (young roots)	74.1
CK (young roots)	74.8
WC (young roots)	74.8
RC (young roots)	74.8
PR (young roots)	75.7
RC (old: tap roots)	75.9
PR (old: 6 gms.)	76.1
CK (old: 6 gms.)	76.9
CH (old: 6 gms.)	79.2
RC (old: 6 gms: tap root)	88.7

For significance at the 5% (1%) level, difference must exceed 3.66(4.88)

A comparison was made of the four treatments that were applied at the two different rates viz: 3 gms. and 6 gms. per pot. These were analysed separately and the results appear in Table XXXII.

TABLE XXXII. The effect of adding grass and clover roots at two different rates on the Percentage Stability of Soil Aggregates 70 days after treatment commenced. Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Replications	3	0.35				
Amount of Added Roots	1	684.50	109.17	4.32	8.02	**
Treatments	3	179.10	28.56	3.07	4.87	**
Amount X treatment interaction	3	14.59	2.33	3.07	4.87	N.S.
Residual	21	6.27				

Coefficient of Variation = 3.3%

** indicates significance at the 1% level of probability.

N.S. indicates not significant.

Comparison of effect of varying amounts of roots: % aggregates retained on a 0.251 mm. sieve.

3 gms.	6 gms.
70.9	80.1

With five treatments, comparisons were available between young roots, harvested four months after sowing and old roots from plants 12 months old. In Tables XXXIII and XXXIV the effect of these two root samples is shown for both the 30 day and 70 day structure determinations.

TABLE XXXIII The effect of young and old root additions on the % Stability of Soil Aggregates 30 days after treatment commenced. Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Replications	3	113.72	16.39	2.96	4.60	**
Age of Roots	1	119.72	16.20	4.21	7.68	**
Treatments	4	41.27	5.58	2.73	4.11	**
Age X Treatment interaction	4	31.54	4.27	2.73	4.11	**
Residual	27	7.39				

Coefficient of Variation = 4.0%

** indicates significance at the 1% level of probability.

Table of Means: % Aggregates retained on a 0.251 mm. sieve.

Species	RC	WC	PR	CK	CH	Age of Roots Means
Old Roots	67.0	71.3	64.6	66.6	65.9	67.1
Young "	76.1	70.5	70.4	68.8	66.9	70.5
Species means	71.6	70.9	67.5	67.7	66.4	

TABLE XXXIV The effect of young and old root additions on the % Stability of Soil Aggregates 70 days after treatment commenced. Analysis of Variance.

Source of Variation	d.f.	Mean Square	F	F Required 5%	F Required 1%	Result
Replications	3	9.08	1.84	2.96	4.60	N.S.
Age of Roots	1	139.88	28.32	4.21	7.68	**
Treatments	4	16.35	3.31	2.73	4.11	*
Age X Treatment interaction	4	17.19	3.48	2.73	4.11	*
Residual	27	4.94				
Total	39					

Coefficient of Variation = 3.1%

** indicates significance at the 1% level of probability.

* indicates significance at the 5% level of probability.

N.S. indicates not significant.

Table of Means: % Aggregates retained on a 0.251 mm. sieve.

Species	RC	WC	PR	CK	CH	Age of Roots Means
Old Roots	71.8	73.8	69.8	67.1	70.6	70.6
Young "	74.8	74.8	75.7	74.8	71.7	74.4
Species Means	73.3	74.3	72.8	71.0	71.2	

Discussion of Tables XXX to XXXIV.

1. In the main the treatments have produced comparable results at each of the two liftings. Although the improvement recorded in structure at the later determination was highly significant, it cannot be concluded that it was due solely to the continuing biological activity in the soil. Experience has shown that different conditions

of temperature and moisture, during the preparation of samples can affect the stability of the soil aggregates. Nevertheless, the result is the expected one with organic material that decomposes slowly. But a stage may be reached when the effectiveness of organic matter may be lost, and the aggregation decrease (85). It is perhaps significant here to note that the only two samples which showed a decrease in aggregation at the later date were red clover samples which had shown rapid decomposition in the Warburg apparatus and gave the highest stability of aggregates in the first determination.

2. Soils from the control pots gave the lowest structure stability. The addition of roots has improved the structural condition of the soil and in practically all cases the improvement is significant.

3. Those pots to which the addition of double quantities of roots was made have consistently resulted in soils with a highly significant improvement in structural stability. Emerson (16) has suggested that this effect and that in (2) is due to the very appreciable contact angle of water advancing into soil containing much organic matter. There is however, some inconsistency in the extent of increase in stability resulting from the larger addition of plant roots.

4. There is a tendency for soils treated with clover roots to be better in stability of structure than those treated with grass roots. In most cases this is significant.

5. The addition of young grass and clover roots has been more effective in improving the stability of soil structure than the use of old roots. This reached a highly significant level in each of the two determinations.

SECTION VI

STRUCTURE IN RELATION TO ROOT CHARACTERISTICS.

A. 4 months Sample.

Correlation coefficients between the aggregate stability and the weight and number of roots present in the soil at the time the stability was measured, were calculated. TableXXXV and Fig. XII show the results of these correlations.

TABLE XXXV Correlation coefficients between aggregate stability and root yield four months after sowing.

Depth	4 Grass species and 2 clover species.	4 Grass species only
0"-2" layer	.513 **	.449 **
2"-4" layer	.259 N.S.	.277 N.S.
0"-4" layer	.514 **	.416 *

* indicates significance at the 5% level of probability
** indicates significance at the 1% level of probability

No relationship existed between the root numbers attached to tillers and the aggregate stability of the soil. Nor was aggregate stability related to the top growth as measured by the yield of herbage at the first cutting period.

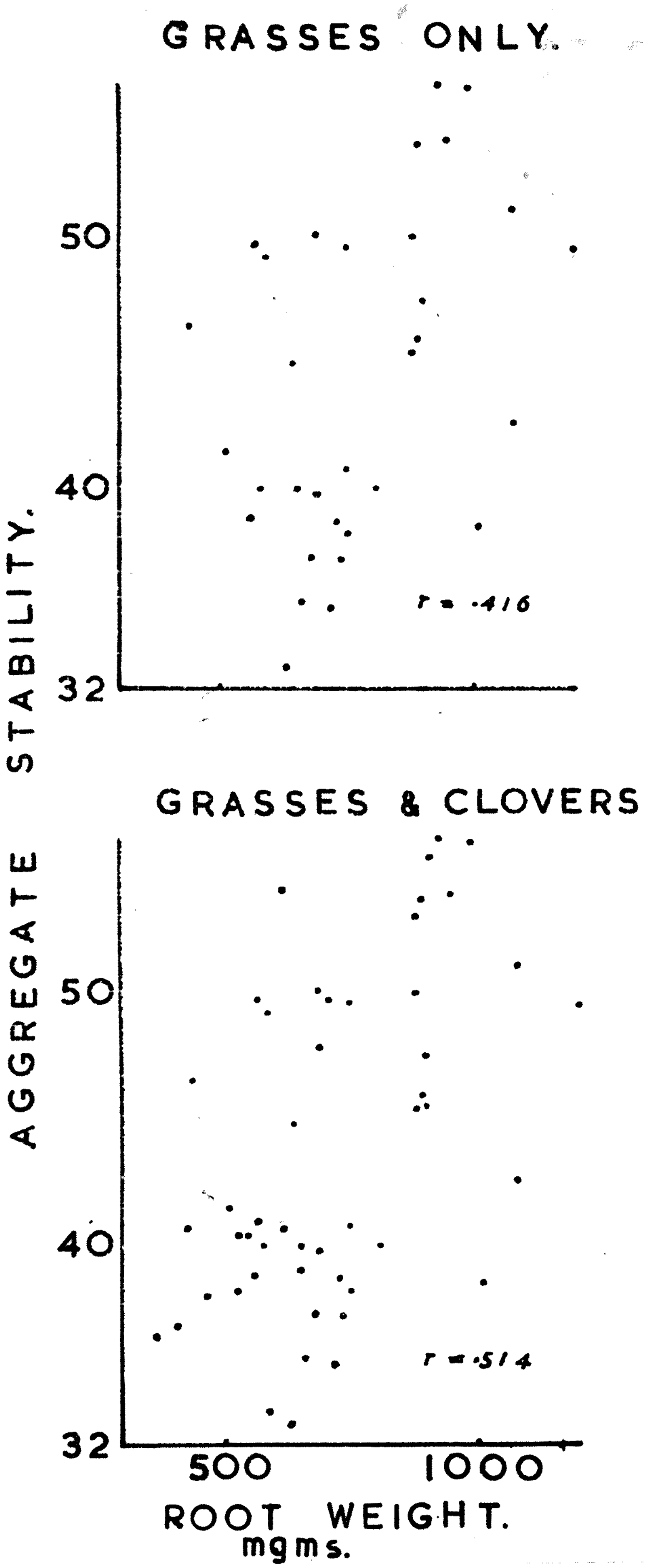

FIGURE XII.

Scatter diagrams showing the relationship between root weight and aggregate stability in the 0"-4" soil level four months after sowing.

B. Eight Months Sample.

No relationship could be established between root characteristics and structure at this stage of development. Grasses only were sampled. Italian ryegrass, the only non-perennial grass, gave the best structure but at this season of the year yielded the lowest root weight. Chewings fescue, perennial ryegrass and cocksfoot occupied the same respective positions in structure stability and root yield but no significant correlation between these two factors could be established because of the marked variation between replicates especially in regard to root weight.

C. Twelve Months Sample.

When grass and clover treatments were considered together a highly significant correlation between root weight and structure was found. This disappeared, however, when attempts were made to relate root weight and structure of the grass species only. As can be seen from Table XXXVI and Fig. XIII similar results were obtained from each of the soil depth sub-samples and in the whole 0"-6" layer.

TABLE XXXVI. Correlation coefficients between aggregate stability and root yield twelve months after sowing.

Depth	3 grass species and 2 clover species.
0"-2" layer	+ 0.444 **
2"-4" layer	+ 0.586 **
4"-6" layer	+ 0.515 **
0"-6" layer	+ 0.635 **

** indicates significance at the 1% level of probability.

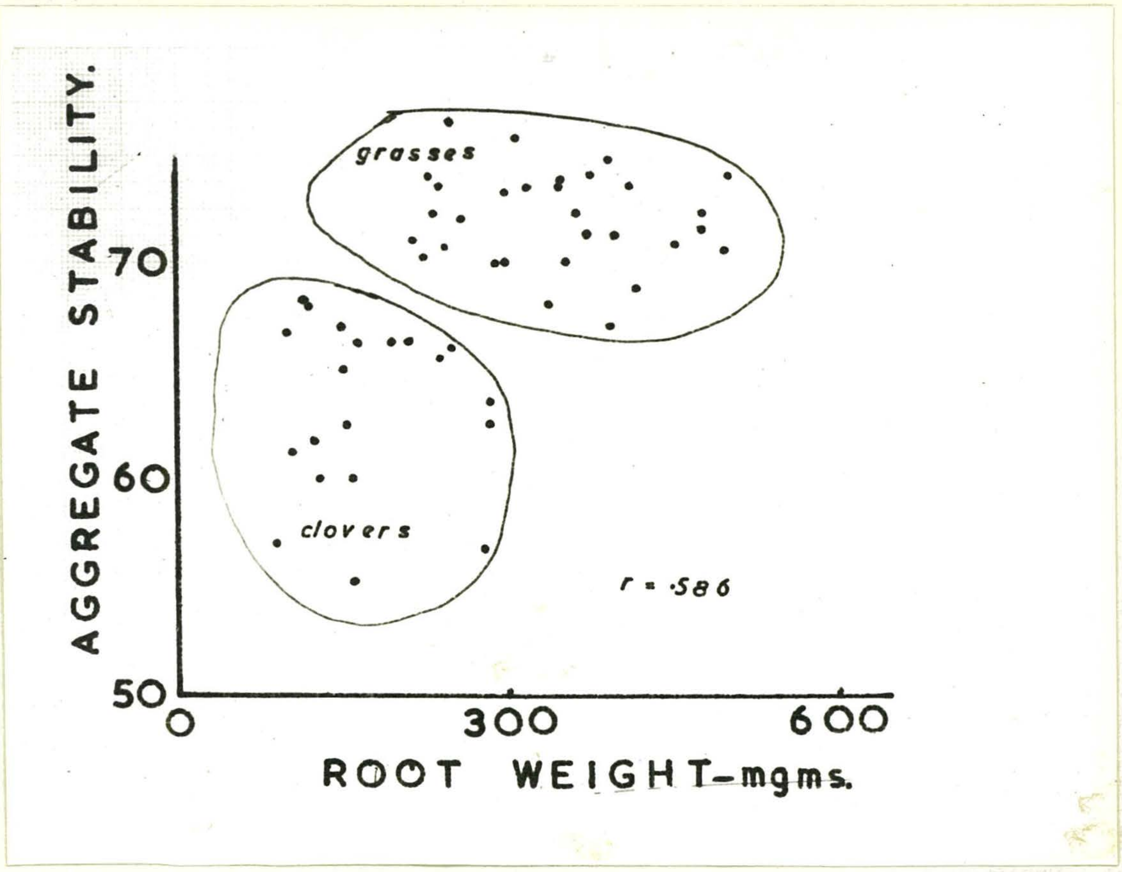

FIGURE XIII.

Scatter diagram showing the relationship between root weight and aggregate stability in the 2"-4" soil level twelve months after sowing. The highly significant correlation is due to most of the grasses being in the "grass group" and most of the clovers in the lower "clover group".

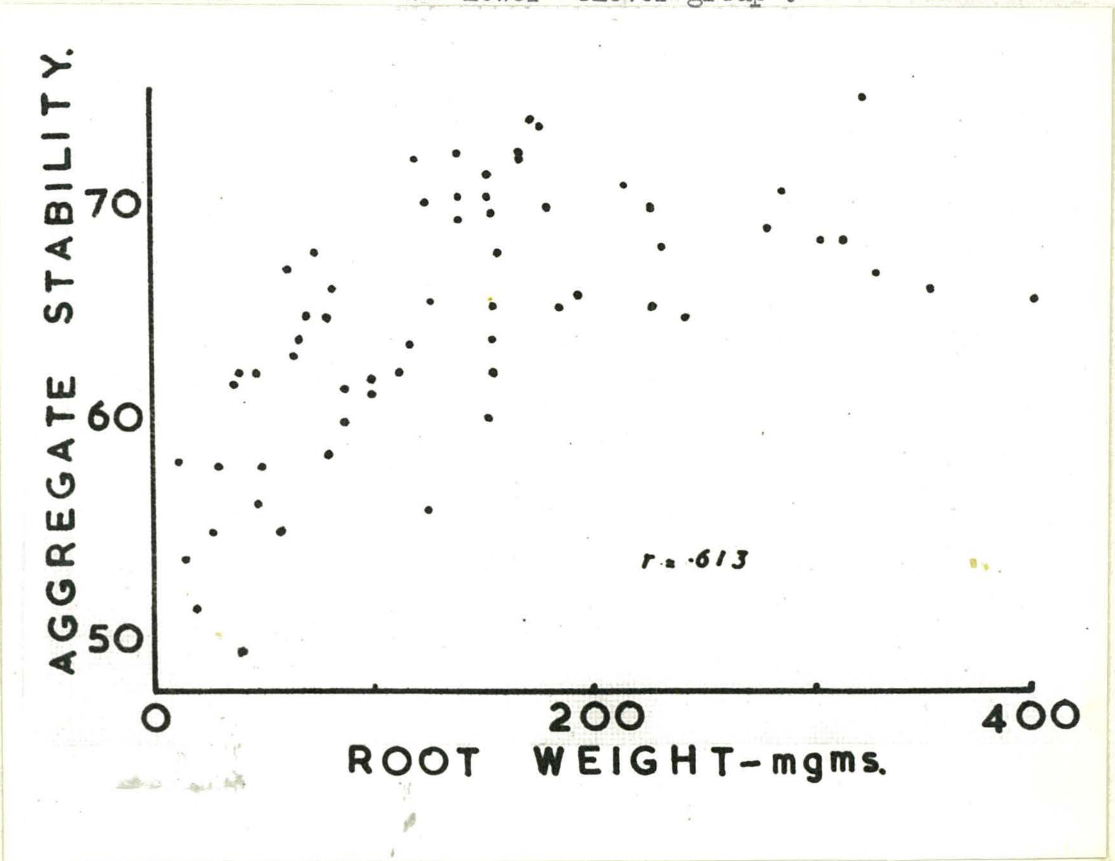

FIGURE XIV.

Scatter diagram showing the relationship between root weight in the 2"-4" soil level and the mean aggregate stability in the 0"-2" and 4"-6" soil levels, twenty months after sowing.

D. Twenty Months Sample.

At this stage of development of the pasture species, a highly significant correlation was again obtained between root weight and structure. (Fig. XIV). This occurred when all plots were included in the calculations. The correlation coefficient was + 0.613 using the root weight in the 2"-4" layer, and the mean structure of the 0"-2" and 4"-6" layers. However, the main object of the samplings at this time was to find out what relationship, if any, there was between root weight and structure within the grass species only. For the number of samples that could be analysed no relationship could be established either using the combined yields of all the species or for each species separately.

E. Pot Experiment

The number of treatments that could be evaluated by the Warburg apparatus was restricted to seven in the first run including two control samples. One sample was lost as a result of teething troubles in using the apparatus. In the second run there were eight samples including two controls; in the third, eight samples with one control; and in the fourth, four samples with one control. Very few comparisons were thus available for establishing any relationship between rates of organic matter decomposition and charges in aggregate stability, and very high correlation coefficients were necessary to obtain significance. Fig. XV and Table XXXVII show the relationship between the rate of root decomposition and the subsequent stability of aggregates.

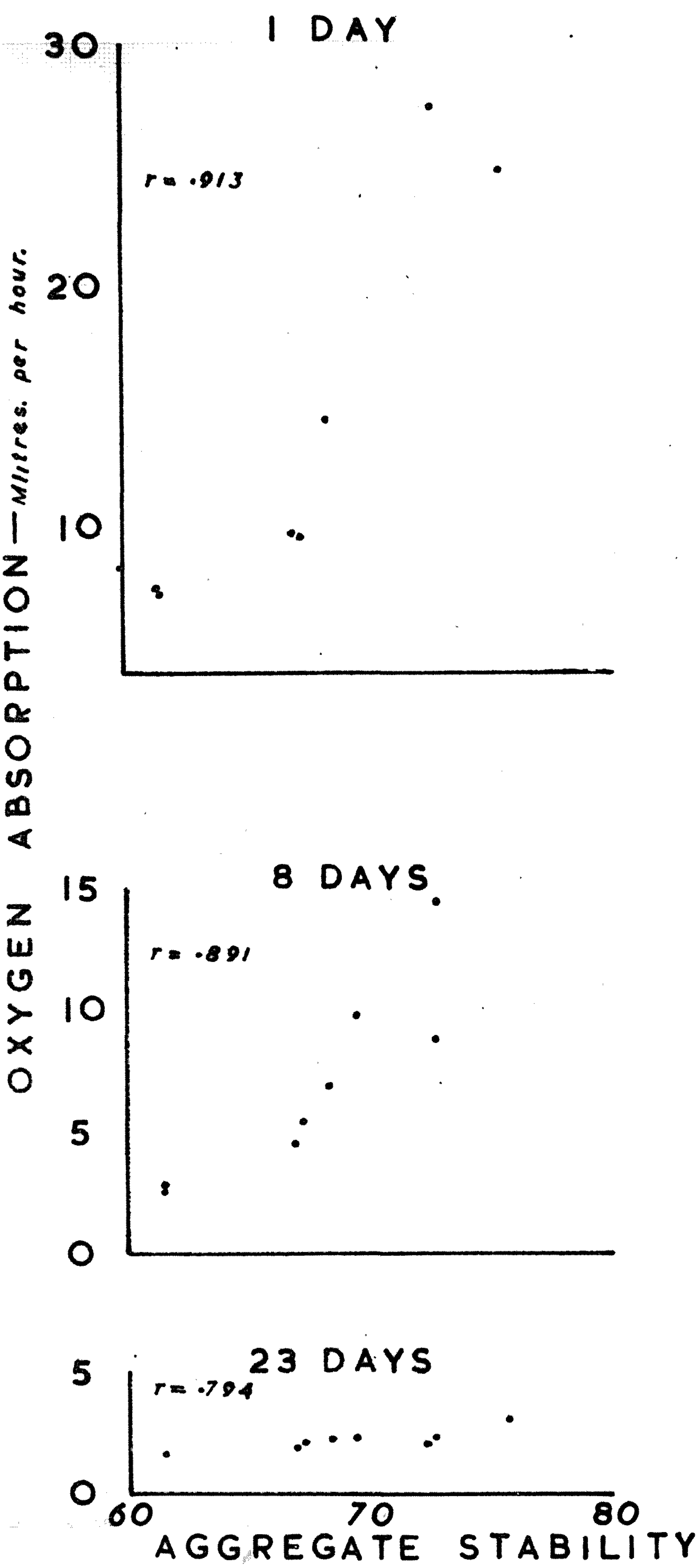

FIGURE XV. Scatter diagrams showing the relationship between oxygen absorption and subsequent aggregate stability of soils ex pots. Aggregate stability is the mean of determinations made after 30 days and 70 days incubation. Rate of oxygen absorption was measured after 1 day, 8 days and 23 days incubation.

TABLE XXXVII Correlation coefficients of stability of aggregates with rate of root decomposition.

	Aggregation 30 days after addition of roots.	Aggregation 70 days after addition of roots.
Rate of O_2 absorption 1 day after moisture added.	.893 **	.890 **
Rate of O_2 absorption 8 days after moisture added.	.846 **	.895 **
Rate of O_2 absorption 23 days after moisture added.	.759 *	.789 *

** indicates significance at the 1% level of probability.

* indicates significance at the 5% level of probability.

Despite the small number of samples a highly significant relationship was found. Before considering the value of this information, it must be remembered that the pot conditions used were highly artificial. The soils comprised dry aggregates of a limited class size, viz., 1 - 3 mm. They had been in an air-dried condition for a week or more prior to the start of this treatment. The added roots had been oven-dried and were thus in an artificial condition, and some changes may have occurred in their organic make-up. These roots were also smashed to small pieces and the internal components were possibly much more readily available to micro organisms than under natural conditions. After wetting, the soils were held at temperatures higher than those experienced in the field and consequently the micro organic population could conceivably have been much different from a normal one for this soil. However, no effort was made to encourage the development of one or more types of organisms as compared with others.

Despite the artificial conditions present, the high significance of the correlation coefficients relating to root decomposition and soil structure improvement indicates that the roots of the species examined show a marked variation in their effect on the physical condition of the soil. By accentuating the differences in root material present, it has been possible to get a very highly significant effect on the resulting structure.

SECTION VII.

DISCUSSION.

Overseas investigations into soil structure have shown that treatments do not necessarily produce the same results on different soil types. Therefore, in this investigation, which has been restricted to a single soil type, no generally applicable conclusions can be advanced. But even if the treatments had been more widely tested, care would still have had to be taken in the interpretation of the results. The treatments under consideration are the effects of growing plants on the soil, and it is impossible to standardise them especially when they are grown out of doors. They are influenced by such outside agencies as climate which can vary the growth pattern from one year to another; or management, which involves stage of cutting or grazing, and nutrient return. Variations caused by these factors could result in markedly different yields of both tops and roots. The managemental conditions prevailing during the course of the experiment have therefore been carefully specified in Section III. Apart from these considerations however, the experiment can be regarded as having helped to explain how pasture plant root growth affects the physical condition of the soil in which the plants are growing.

Discussion of the results has been divided into the following sections:-

(a) The effects of the treatments on soil structure.

(b) Study of root development of the species used.

(c) The role of pasture plant roots in soil structure development.

(a) The Effects of the Treatments on Soil Structure.

The difficulty of measuring the short term improvements in structure were increased in this experiment by the fact that the soil on which the plots were sown was not showing advanced deterioration of structure. The effect of at least fifty years in pasture had not been entirely removed by the three years of cropping, which the soil of the A plots had experienced. However it appeared to be on the verge of a greater collapse if the experience of the B plots which had had an additional year's cropping is any indication. Unfortunately, at the time of sowing the A plots the technique to be used throughout the experiment for aggregate analysis had not been worked out. But its percentage stability is certain to have been considerably higher than the 34.7% of stable aggregates recorded for the soils of the B plots at the time they were sown a year later. (See Appendix X). In comparing the aggregate stability of the two soils four months after the sowing of each, some idea of the difference between them can be realised. The mean of the six treatments of the A plots in August 1952 was 60.8% stable aggregates while in August 1953, the same six treatments in the B plots gave a mean value of only 40.8% of stable aggregates. Granting that differences in season and management may have made some difference, the indications are that the extra years cropping has made a considerable impact on soil structure deterioration. This means that the soil of the B plots, starting off in poorer condition, would have given a greater opportunity for a good structure improving treatment to have shown itself, had it been possible to carry these plots on for a longer period. Over the first eight months the treatments showed a greater range of effects on the soils of the B plots than on those of the A group which started off in better condition physically. However, some of this difficulty was overcome by the ample replication of the treatments and by reducing the experimental error to a minimum through standardisation of the analyses.

The outstanding feature of the structure results was the superiority of the grass treatments in improving aggregate stability. But the wet sieving technique failed to separate the individual grass species despite the fact that considerable differences were evident to the eye in the soils from the different treatments. Efforts to illustrate these typical structures by photography were also unsuccessful, as they involved not only such features as the fineness and shape of the natural aggregates, but also the readiness with which the soil disintegrated under pressure when dry or slightly damp. The only figures which indicate any difference between the three grass species were obtained during the dry sieving of the soils for the 3-6 mm. fraction. The latter figure recorded as a percentage of the total soil from which it was removed showed consistent trends with each species, (Appendix V) especially in the top two inch level. Only 30% of this soil in the Chewings fescue plots was retained on a 3 mm. sieve. 39% of the soil of the cocksfoot plots was retained and 45% of the perennial ryegrass soil. These figures bear out the observations on the soil structure made during the course of the experiment.

It was noticeable that under ryegrass, the soil structure was consistently cloddy in nature. There was difficulty in breaking up the larger lumps into smaller granules once they had dried out, and, when they did break they tended to produce sharp edged particles. In this respect the structure was like that of the clovers, particularly white clover. But they reacted quite differently under wet sieving. There was a harsh feel about the soil which may have contributed in the past to farmers' comments that ryegrass was not as good as cocksfoot in structure improvement.

The soil from the cocksfoot plots broke up into what seemed to be natural aggregates much more freely. The ramification of fine roots through the soil was more noticeable and the granules were generally rounded, and a big proportion of them were of pea size. The term "crumb structure" adequately described the condition of this soil, which had a soft, mellow feel and even large lumps of air dried soil broke down evenly under light pressure.

The soil from the Chewings fescue plots showed practically no trace of cloddiness. It broke down easily when being dry sieved into smaller particles than those of the cocksfoot plots. These natural aggregates had rounded surfaces, and were frequently bound to each other by grass roots which had formed a densely ramifying mass in the top inch of the soil. In some cases in the 0 - 2 inch samples, it was difficult to separate the soil particles from the root mass, and the extra manipulation required as a result may have caused an excessive break down of the soil during dry sieving. It was obvious however, that this soil was more finely divided than those of the other grass species, and this is borne out in the analyses which were carried out on the unscreened soil samples and recorded in Table V. As will be seen from Appendix V there were highly significant differences between all three species in the top two inch level, ryegrass differed from the remaining two in the 2 - 4 inch level, and no significant differences were apparent in the 4-6 inch level.

As the wet sieving technique for structure stability was not able to separate the three species, it can be concluded that, despite the different appearance of the soils, the individual aggregates in each reacted very similarly to the disintegrating effects of water and therefore that the mechanism of water stability was much the same in each case. Even abrasion caused through shaking the samples in water prior to sieving failed to produce any differential response and indicated also that the water proofing effect noticed in all the top two inch samples of the grasses and in particular with Chewings fescue was not causing an error in the wet sieving analysis.

The second important feature of the treatment effects was that the soil from the white clover plots was superior in aggregate stability to that from the red clover plots, and that both showed a vast improvement over the bare ground soils. In appearance, the three soils presented little if any noticeable differences, although the bareground soils tended to become powdery when dry. All three were rather difficult to break down to pass through a 6 mm. sieve when air dried, red clover being the least troublesome in this respect. The

3 - 6 mm. particles were predominantly angular in shape, and many of them had a tendency to collapse when immersed in water, the bare ground soil being more seriously affected in this respect, but no evidence of explosive shattering of such aggregates was found. All three soils were readily wetted when immersed.

Some explanation of the improvement of the structure of the bare ground soils during the course of the experiment is required, and there are two possible reasons for this change:-

1. As the loss on ignition figures indicate, (Appendix IV) there was a considerable reserve of organic matter in the soil at the start of the experiment. This had been maintained by previous crop residues which had been worked into the soil and fed off with sheep. And although the maize crop grown just prior to sowing down the plots had been pulled out and removed, a considerable amount of root material was certainly still left in the soil. Now the literature shows that organic matter plays a very important part in structure improvement and no doubt, in this case there was sufficient present to be responsible for some of the improvement recorded. During this time structure destroying factors such as cultivation would be at a minimum.

2. Although this treatment was kept as free as possible from vegetation, complete control was not obtained. Some organic matter therefore was returned to the soil in the top growth that was scraped off at the time of hoeing and left lying on the surface of the plots. Some would be returned in the roots of the plants also. Worms were active near the surface of this plot, and would help to incorporate organic matter throughout the soil.

Although comparisons between liftings are not strictly valid, the change in aggregate stability over the twenty month period is sufficiently regular and of such magnitude to leave no doubt about it being real. (Fig. XVI). Seasonal variations which have been reported from America (104), and variations resulting from possible different experimental conditions at different liftings have apparently been

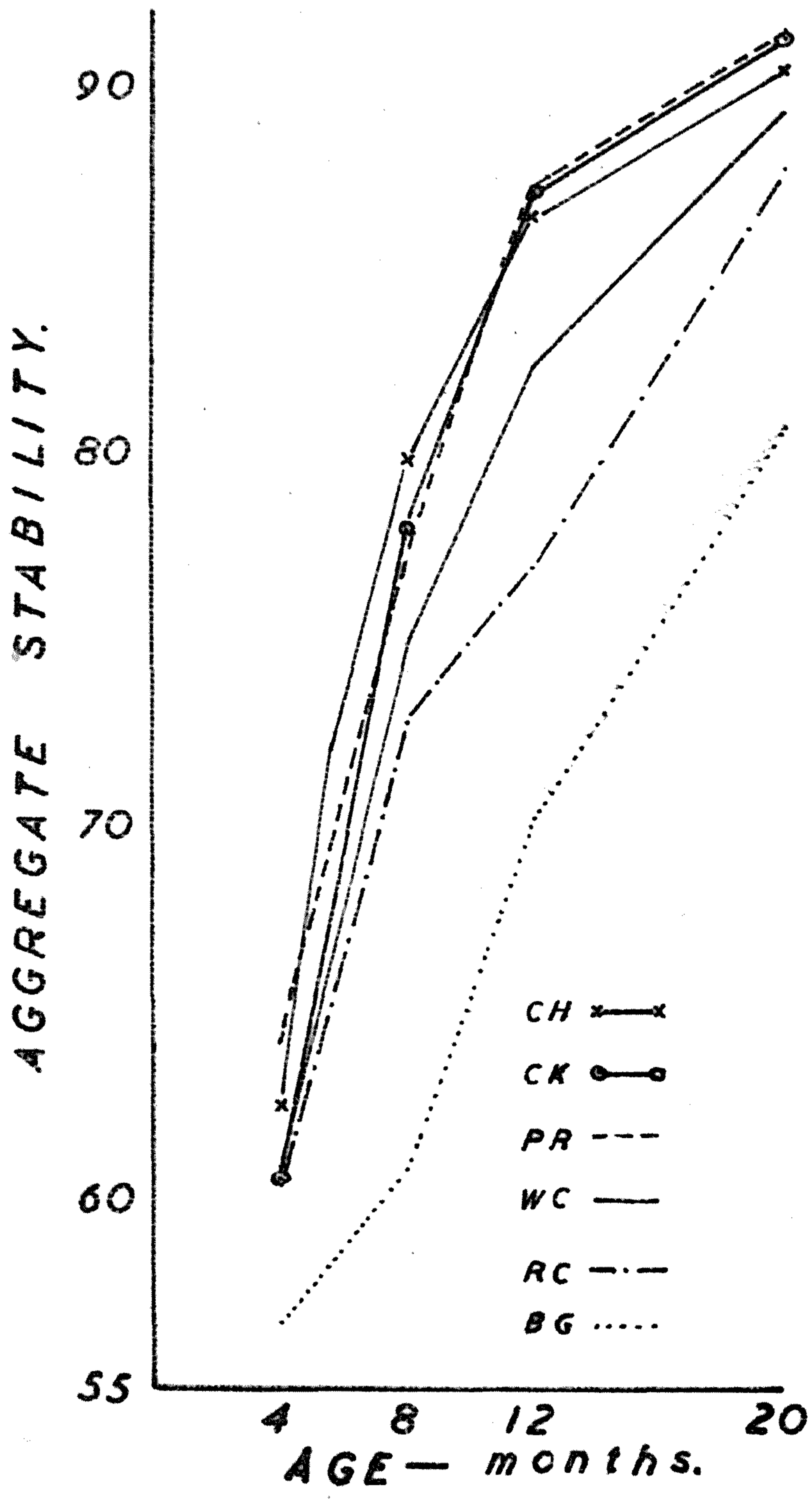

FIGURE XVI.

Graph showing changes in aggregate stability of the six treatments during the experimental period of twenty months.

(Data not transformed to angles.)

masked by the greater effects of the treatments. It appears also that, as measured by the technique described, the structure has almost reached that of a neighbouring old pasture which can be regarded as having maximum stability. This is in agreement with Russian (26) rather than British experience (39), the latter finding that the structure build up was incomplete even after 25 years. It is possible however that a more searching technique would show up the old pasture soils in a better light. It is intended that, after three years from sowing, the plots will be cropped, and a record of downward structure changes will be kept and compared with those from similar treatments given to a neighbouring virgin soil. From these results it should be possible to decide how efficient this wet sieving technique is in judging the structure of soils in better than average conditions.

In the two later liftings of the A plots, separate analyses were made on 0 - 2 inch, 2 - 4 inch and 4 - 6 inch depths. Stability decreased with depth in every case and generally there was little if any variation in the relative position of each treatment at the different depths. It was found however, that in the top two inch level, the clover and bare ground soils more closely approached the grass soils than in the other two depths. An explanation of this is offered in (c) of this section. Structure stability decrease with depth is normal (94), and the results of Watkins (95) on an adjacent alluvial soil where he found the greatest degree of aggregation in the 4 - 6 inch soil level are unusual. Among the three grasses the pattern of variation with depth varied considerably. As already indicated differences between them at the three depths for the 12 month and 20 month samplings were not significant. But at both these times, in the 0 - 2 inch level ryegrass tended to be superior to cocksfoot which in turn was superior to Chewings fescue in aggregate stability. As the depth increased, so did Chewings fescue improve its position relative to the other two species so that in the 4 - 6 inch level it was the best. (Tables XVII & XIX). The fact that this occurred at two widely separated sampling times and over a large number of replications gives some credence to it being real. Observations of the 0 - 2 in. samples of screened soil used for wet sieving analysis showed that the Chewings fescue contained a great proportion of its particles near the minimum size i.e. 3 mm., cocksfoot a less number and perennial ryegrass fewer still. This appears to have had its effect on the amount of soil retained on the 1.676 mm. sieve. The analysis of the complete soil samples taken at the 12 month lifting also confirms the deficiency of Chewings fescue in the top 2 inch level. (Table V). This gives a figure for aggregate-size distribution and shows that the Chewings fescue sample is even poorer than the bare ground sample in this respect. Stability of structure may have occurred, but the size of many of the aggregates so stabilised must be small enough to pass through a 0.251 mm. sieve. It would seem that root ramification has proceeded to a stage that has exceeded the requirements necessary for the building up of aggregates of a size normally associated with satisfactory tilth conditions, i.e. somewhere in the region of 2 mm. in diameter.

In the B plots, one might have expected the krilium treatment to have given similar results in the 2 - 4 inch level as in the 0 - 2 inch level. However, the effect of depth has been rather similar to that found in other treatments. The decrease in the 2 - 4 inch level is not as great as the average, but there is then a big drop to the 4 - 6 inch level. (Table XVII). The only explanation of this is that, when the krilium was spread on the surface and worked in to a depth of six inches, the distribution of it evenly throughout this depth was not as satisfactory as was anticipated.

(b) Study of Root Development of the Species used.

The management given to the plot area was adjusted so as to produce a high measure of root development in all the species. (28). To this end, the plots were allowed to make maximum growth before the herbage was trimmed. It was thought that in this way any effects of roots on soil structure would be as pronounced as possible and that differences in root characteristics would be more easily distinguished. In addition, this type of management, by maintaining an almost pure cover of the sown species in each plot, also made it more certain that the effects were due to the species itself and not to invaders.

It was decided at the outset that because of the work involved to limit the main root studies to a determination of root yields and decomposition rates of dead roots. This was because improvement in soil structure has been shown to be induced by both the quantity and quality of the organic matter additions to the soil and the above two root characters would help to tell the story of what was going on in each plot. The information really required was the extent of both new root growth and old root death throughout the experimental period. But unfortunately no satisfactory method of determining the longevity of roots in any particular situation has as yet been devised. Hence the rate of addition of organic root residues to the soil is not known and even if it were possible to find out how long roots normally lived, the position would be complicated in pasture by the following factors:-

1. The cortex of grass roots may slough off before the root ceases to function as a means of translocation.

2. Root caps and root hairs are being continually returned to the soil. The latter seem to live for varying lengths of time and secondary root hair production may also occur. Their significant importance may be guaged by Dittmer's (12) estimate of 0.2% of the soil volume being occupied by the root hairs of <u>Poa pratensis</u>.

3. Plants die as a result of both seasonal climatic conditions

and interplant competition, factors which can vary greatly in their effects. Rootweight, therefore, recorded at any one time gives a poor indication of past root development, and differences in yield between successive samplings are also of little value in determining the new growth or root decay in that time. Recent work by Schwass at Massey College has shown that white root numbers and weights taken at intervals over a period of some months can present a satisfactory picture of new root growth. Knowing total root weight, new root weight and the length of time that new roots remain white, one would be in a much better position to estimate the amount of dead roots returning to the soil. White roots can be conveniently separated from pot grown plants, but under sward conditions attempts to use this system proved unsatisfactory. The number of all crown roots showed marked variation from species to species, but gave no indication of root intensity, as branching below the crown varied greatly in extent.

The quality of root material in improving soil structure has been estimated by Pavlychenko (61) in terms of a "soil binding equivalent". This proved a satisfactory expression for indicating root development and resistance of those roots to decay, but it involved difficult measurements of root-length, mean root diameter and tensile strength. In this experiment it was decided that the rate of decomposition of roots could be more easily determined by means of the Warburg apparatus. The standardised pot trial also presented an opportunity of directly relating structure development with rate of root decomposition. Conclusive evidence was obtained in regard to decomposition rates, the legumes, as expected, showing more rapid decay than the grasses. The effectiveness of the technique was checked by varying the quantity of roots added to the soil, and although the rate of breakdown was not proportional to the roots added, the samples showed that biological activity was increased by increased additions. The more rapid breakdown of young roots was also demonstrated. The full value of the pot trial was limited by the fact that it was not possible to extend it over a period of a year or more. This would have given an opportunity of following the deterioration of the more slowly decomposing roots. Unfortunately the apparatus was not entirely suitable for this purpose. The trial might have been expected to show up differences between the grass species in view of the marked differences in the diameter of the individual roots. But there were not even any trends noticeable, let alone significant differences.

Root length would have been of value for comparative purposes, as a knowledge of this would have enabled something more definite to have been said in regard to the effect of the degree of intimacy of roots and soil on structure development. However, in order to obtain figures suitable for statistical analysis, the time spent (on the basis of Pavlychenko's work) would have been out of proportion to the results obtained. Consequently the extent of root ramification could only be estimated by eye appraisal assisted by the two factors, root diameter, of which a restricted number of measurements were taken under the microscope, and total root weight. The general conclusion from these was that, under the conditions prevailing, the species could be arranged in the following descending order of root length per unit volume of soil:-

Chewings fescue
Cocksfoot
Perennial ryegrass
White clover
Red clover.

It seems that further investigation of root length would be worth while because it would indicate the extent of the intermingling of the roots with the soil, a factor which may be of importance in soil structure development and maintenance not only while the roots are alive but after they have died.

The distribution of roots in the different soil levels is worthy of comment, because although the actual quantities varied extensively between species, the proportion of roots in the top soil level was almost identical for each species. Approximately two thirds of the total roots found in the six inch level examined, were present in the top third of it, i.e. the 0 - 2 inch level. The variation in structure decrease between species could not therefore be accounted for by varying decreases in root weight. Weaver (96) has shown that species normally do show variation in their root distribution through the soil profile, particularly where depths greater than the 6 inches used here are taken into consideration.

(c) The Role of Plant Roots in Structure development.

The importance of organic matter in the development of structure has been recorded in Section II, and pasture plants almost certainly react on soil structure mainly through their organic residues, particularly dead roots, left in the soil. This experiment indicates that living roots too may have some effect, because within four months of sowing, all soils on which species had been sown were highly significantly superior to the unsown bareground plot. This improvement could have resulted through the formation of surfaces of fracture in the soil mass through the penetration of roots and the drying out of the soil adjacent to them. The stabilising of the soil on these surfaces could be through the agency of bacterial and fungal activity consequent on the shedding of root caps and root hairs or on the excretion of organic compounds from the roots. The important feature is that there was a significant relationship between the amount of grass roots and the structure at this early stage which is one time when the yield of roots recorded was likely to be a good indication of what had actually grown there in the previous four months. It would not be entirely so, however, because a certain amount of competition between plants in the establishment period would have caused some deaths. The roots of these plants would become available for breakdown by the soil micro flora. Some loss of seminal roots would also have occurred in the surviving plants.

On the other hand the pot experiment shows conclusively that dead roots are effective in stabilising structure even if their distribution is not all it might be. For the short time that the pot experiment was running, the best improvement in structure came from the rapidly decaying roots. This is in agreement with Martin & Waksman (46), but as Stallings (85) points out this structure stability could reach a peak and then decline. The more slowly decomposing root material might then at some more distant time have proved itself superior. It is clear that more accurate information on the changes taking place in the soil organic matter content of the plots would have enabled a better interpretation of the results. The method used to indicate organic matter content was the loss on ignition. This was determined for each plot at each sampling time, but the method was not sufficiently accurate to present more than a general picture of organic matter changes during the course of the experiment. (Appendix IV). The figures showed an upward trend, with no treatment standing out.

There was no correlation between root weight and structure at the later liftings. This is in agreement with Feng's results quoted by Ward (94). The only report of root weight being correlated with structure, apart from the four month's figures reported here, is from Williams at Hurley (102). In his plots he had mixed sowings of grasses and clovers and, where such is the case, a false conclusion can be reached if a correlation is attempted. This is demonstrated clearly in Table XXXVI where a highly significant relationship was established between root yield and stability when clovers and grasses were combined in the calculation. All that has been done is to combine clover figures which are low in both characteristics and grass figures which are high in both, and a significant result must be obtained. But it is clear that there are other unknown factors operating which make it impossible to gain a significant result when only clovers or grasses are considered at a time. So that William's correlation would appear to be merely the result of more or less clover being present in his samples and giving a lower or a higher structure respectively. Any yields of roots taken after the establishment period will not indicate the extent of the total root initiation to date, because of the unmeasureable amount of root decay that has taken place along with new growth, and more will have to be known about these two factors before the full story of the effect of grass and clover roots on soil structure can be written.

In all pastures some of the leaves and stems of the grasses and clovers die back and find their way onto the soil surface. As they decay, they are incorporated into the soil by worms and other micro flora. In the plots under consideration, this occurred to a greater extent than if grazing had been practised. It was noticeable that the clover leaves in particular were inclined to drop and undoubtedly there was a considerable return of organic matter to the soil in this way. It is possible that this explains why it was found that in the top two inch level, the clover soils more closely approached the grass soils than in the other two depths. (See Table V.) The bare ground plot also shows this rather high surface stability and this can be accounted for in the weed residues which were left on the soil surface after hoeing. Worm activity was particularly noticeable in these plots, and assisted in incorporating the organic matter into the soil.

The investigation as a whole, then has demonstrated that there is a close relationship between pasture plant root growth and the structure of the soil supporting those plants. The relationship however is not a simple one. The build up of structure to a great extent acts indirectly through the soil microflora and our information on structure will not be complete until a lot more is learnt about what is required by the soil flora and fauna for their optimum growth.

SECTION VIII.

SUMMARY AND CONCLUSIONS.

The following is a summary of the results and the conclusions reached during the course of the experiments.

(1) A satisfactory technique for assessing structural changes in the soil concerned was evolved.

(2) Under the conditions existing in the experimental plots, the grass species were more efficient in building up soil structure than the clovers which in turn were better than the bare ground treatment.

(3) Further information is required on the longevity of pasture plant roots.

(4) Quickly decomposing root systems were found to have a more rapid improving effect on soil structure for a start than those which decompose slowly. A longer term experiment is necessary to determine whether the same applies in the long run. Decomposition effects can be overshadowed under pasture conditions by other factors such as bulk of root growth.

(5) The grass species yielded a heavier crop of fibrous roots than the clovers at each of the sampling dates.

(6) The two tufted grasses per se did not appear to have any advantage over the rhizome forming grass used in the experiment in regard to soil structure improvement.

(7) It appeared that, up to a point, intensity of root development was advantageous in the formation of water stable aggregates of satisfactory size. Very intense root growth however tended to reduce the aggregates to a size normally regarded as below the optimum for the production of good seedbed conditions.

(8) As a result of observations made in this experiment, it is considered that the best type of plant for structure improvement would be one with roots that were quick growing, widely ramifying, short lived and easily decomposed.

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ACKNOWLEDGEMENTS.

Thanks are due to the Grasslands Division, D.S.I.R. for the supply of seed used in the plot sowings, and for the loan of the Allen motor mower. Sampling difficulties were much reduced by the use of a seed sampler provided by the Seed Testing Station, Department of Agriculture.

The helpful advice and assistance of Mr. A.C. Glenday in statistical problems associated with the investigation is much appreciated.

In addition, the design and construction of the soil sampler and sieving apparatus was facilitated by the co-operation of several members of the College and Dairy Research Institute staffs.

APPENDIX I

Grade of Grass and Clover Seed Used in Plot Sowings

1952 A. Plots

Species	Grade	"Grasslands" Station No.
Perennial ryegrass	Certified Pedigree	Ba.51
Cocksfoot	Certified Pedigree	Bc.617
Chewings fescue	Commercial	Bl.115
White clover	Certified Pedigree	Ac.30
Red clover (cowgrass)	Certified Pedigree	Aa.750

1953 B. Plots

Species	Grade	"Grasslands" Station No.
Perennial ryegrass	Certified Pedigree	Ba.61
Italian ryegrass	Certified Pedigree	Bb.412
Cocksfoot	Certified Pedigree	Bc.630
Chewings fescue	Commercial	Bl.116
White clover	Certified Pedigree	Ac.30
Red clover (cowgrass)	Certified Pedigree	Aa.764

APPENDIX II

Manurial Treatment of Grass and Clover Plots

A. Plots

30.7.52	28 lb. nitrochalk per acre
	56 lb. serpentine superphosphate per ac.
10.10.52	140 lb. sulphate of potash per acre.
	56 lb. nitrochalk per acre.
	112 lb. serpentine superphosphate per acre.
5.5.53	112 lb. sulphate of ammonia per acre.
	224 lb. ground limestone per acre.
	112 lb. serpentine superphosphate per acre.
7.9.53	112 lb. sulphate of ammonia per acre.
	112 lb. serpentine superphosphate per acre.

B. Plots

5.5.53	112 lb. sulphate of ammonia per acre.
	224 lb. serpentine superphosphate per acre.
7.9.53	56 lb. nitrochalk per acre.
	112 lb. sulphate of potash per acre.
	112 lb. serpentine superphosphate per acre.

APPENDIX III

Herbage Yields from A Plots.

I. Pounds per Plot of 10ft. by 3 ft. (Green Weight)

(a) Cut 8th October, 1952.

Block No. Treatment	I	IF	II	IIF	III	IIIF	IV	IVF	V	VF	Total
Perennial	3.5	3.3	3.0	2.6	2.7	2.5	3.3	3.4	3.5	2.4	30.2
Cocksfoot	0.8	0.8	0.7	0.9	0.5	0.9	0.8	0.8	0.6	1.2	8.0
White Clover	5.2	4.6	5.0	4.2	1.9	4.4	4.1	4.6	4.4	5.6	44.0
Red Clover	2.7	2.6	3.3	2.3	4.2	4.0	3.8	3.9	4.2	3.9	34.9

(b) Cut 8th December, 1952.

Block No. Treatment	I	IF	II	IIF	III	IIIF	IV	IVF	V	VF	Total
Perennial	2.1	2.1	2.6	2.2	2.5	1.9	2.6	1.2	2.1	2.8	22.1
Cocksfoot	5.4	3.2	4.2	3.3	4.8	3.6	3.0	5.1	3.1	4.5	40.2
White Clover	1.3	1.1	1.7	1.5	1.6	2.0	0.7	1.3	1.5	1.0	13.7
Red Clover	8.4	10.1	11.1	10.6	11.7	9.3	9.0	10.8	11.9	5.5	98.4

(c) Cut 3rd February, 1953.

Block No. Treatment	I	IF	II	IIF	III	IIIF	IV	IVF	V	VF	Total
Perennial	0.5	-	-	-	-	-	-	0.5	0.25	-	1.25
Cocksfoot	4.0	1.25	2.0	1.75	1.0	2.25	1.5	2.5	2.0	4.25	22.5
Chewings F.	1.25	1.5	0.75	0.75	1.25	0.75	0.75	1.75	1.0	0.25	10.0
Red Clover	7.75	9.0	12.25	7.5	11.25	14.0	11.25	11.25	10.25	7.25	101.75

APPENDIX III (continued)

(d) Cut 4th May, 1953.

Block No. Treatment	I	IF	II	IIF	III	IIIF	IV	IVF	V	VF	Total
Perennial	8.25	5.75	9.25	8.25	6.75	7.75	8.25	6.25	11.25	9.25	81.0
Cocksfoot	13.25	13.25	15.25	13.75	15.75	18.25	13.25	17.75	14.25	18.75	153.5
Chewings F.	11.25	13.25	10.25	13.75	10.75	12.75	9.75	7.75	12.75	7.75	110.0
White Clover	6.25	3.25	2.25	8.25	3.75	6.75	6.25	6.75	5.75	6.25	55.5
Red "	7.25	6.75	6.25	5.75	6.75	8.75	11.25	7.75	9.75	5.75	76.0

(e) Cut 21st October, 1953.

Block No. Treatment	I	IF	II	IIF	III	IIIF	IV	IVF	V	VF	Total
Perennial	10.7	10.8	9.0	10.0	9.6	10.0	15.4	18.6	14.4	14.7	123.2
Cocksfoot	12.4	6.8	12.1	10.1	12.9	11.1	10.2	16.4	14.5	15.4	121.9
Chewings F.	6.0	5.3	3.2	6.9	9.2	5.2	9.0	14.3	10.1	9.9	79.1
White Clover	14.6	9.7	11.7	13.7	9.9	12.9	14.5	13.4	14.7	13.8	128.9
Red "	15.5	11.3	11.0	14.1	16.4	13.9	15.6	16.8	15.8	14.3	144.7

(f) Cut 31st December, 1953.

Block No. Treatment	I	IF	II	IIF	III	IIIF	IV	IVF	V	VF	Total
Perennial	4.2	3.9	4.0	2.6	4.2	3.3	4.4	4.6	5.5	5.6	42.3
Cocksfoot	10.2	9.3	10.7	7.6	10.9	9.5	9.6	10.8	11.6	13.1	103.3
Chewings F.	5.8	6.5	4.9	5.7	6.3	4.7	4.6	5.1	4.8	6.2	54.6
White Clover	6.3	4.6	4.9	8.8	3.6	6.3	4.7	3.0	3.4	4.0	49.6
Red "	15.5	19.5	17.2	13.9	21.4	17.4	18.3	18.2	14.9	13.1	169.4

APPENDIX III (continued)

II. Percentage Dry Matter and Dry Matter Yield Per Acre

Cutting Date.	PR		CK		CH		WC		RC	
	%D.M	D.M. per ac. (lb)	%D.M	D.M. per ac. (lb)	%D.M	D.M. per ac. (lb)	%D.M	D.M. per ac. (lb)	%D.M	D.M. per ac. (lb)
8.10.52	22.9	1003	24.4	284	-	-	14.4	921	17.5	887
8.12.52	30.4	976	23.4	1366	-	-	18.0	358	16.4	2343
5. 2.53	28.6	52	23.6	771	33.2	482	-	-	28.8	4255
4. 5.53	32.3	3799	28.2	6285	29.7	4744	15.1	1217	26.9	2968
21.10.53	21.9	3920	24.4	4322	25.8	2965	13.2	2472	14.9	3133
31.12.53	30.6	1881	30.6	4593	31.8	2523	19.9	1434	22.3	5489
Total		11631		17621		10714		6402		19075

APPENDIX IV

I. Moisture Content of Soil at Time of Sampling for Structure Analysis.

(% of oven-dried soil)

(a) A Plots

Date of lifting Treatment	August 1952	December 1952	April 1953	December 1953
PR	39.3	35.9	31.6	30.7
CK	37.4	31.1	28.4	26.6
CH	37.4	29.4	27.6	26.5
WC	33.4	29.7	28.4	27.4
RC	34.4	32.3	29.9	25.8
BG	35.1	27.6	30.7	25.5
Mean	36.2	31.0	29.4	27.1

(b) B Plots. September 1953

PR	38.7
CK	39.1
CH	38.3
WC	37.7
RC	38.5
BG	37.0
IT	37.7
KR	35.5

APPENDIX IV (continued)

II. Loss on Ignition of Soils Used
for Structure Analysis.

(% of oven-dried soil)

(a) A Plots

Date of lifting Treatment	August 1952	December 1952	April 1953	December 1953
PR	7.9	7.3	7.8	9.4
CK	8.1	7.3	8.9	9.0
CH	8.7	8.2	8.2	9.0
WC	7.7	7.5	8.2	7.8
RC	8.2	7.4	8.6	9.1
BG	8.1	8.3	8.1	8.6
Mean	8.1	7.7	8.3	8.8

(b) B Plots

PR	8.6
CK	8.8
CH	8.4
WC	8.5
RC	8.2
BG	8.1
IT	8.1
KR	8.3

APPENDIX V

Structure Analyses

I. Four Month Samples

(a) A Plots

1. % 3-6 mm. air dry soil retained on 1.676 mm. sieve.

Block No	Sampling Position	Duplicate No.	PR	CK	CH	WC	RC	BG
I	A	1.	57.6	58.6	57.2	58.4	58.2	55.2
		2.	57.6	58.6	59.0	56.4	58.0	54.2
	B	1.	72.4	66.4	67.2	59.0	61.0	57.6
		2.	68.4	62.0	68.2	57.6	62.2	56.8
IF	A	1.	64.8	60.0	60.8*	56.4	61.2	57.8
		2.	63.2	60.0	60.8*	54.8	63.4	54.8
	B	1.	66.6	61.2	68.2	64.2	60.6	54.8
		2.	66.4	61.0	70.6	65.8	60.6	56.0
II	A	1.	61.0	62.2	60.2	60.4	59.6	52.4
		2.	60.4	56.6	58.0	62.6	59.0	52.4
	B	1.	67.0	58.0	61.6	59.0	56.8	57.8
		2.	64.4	56.8	58.6	59.0	58.2	53.8
IIF	A	1.	62.8	53.0	55.6	64.6	54.0	56.6
		2.	64.6	57.2	56.8	63.2	53.2	56.2
	B	1.	60.2	59.0	64.2	60.6	60.4	58.6
		2.	66.0	58.0	59.4	61.6	60.2	55.2
III	A	1.	63.8	61.2	58.2	59.2	51.2	54.2
		2.	66.8	62.6	56.6	60.6	53.2	54.6
	B	1.	64.8	62.0	59.8	63.4	60.8	58.6
		2.	59.2	60.6	60.0	58.0	59.2	52.6
IIIF	A	1.	63.0	58.4	63.2	62.4	64.4	62.4
		2.	65.6	64.2	62.0	59.2	61.6	60.8
	B	1.	56.6	54.4	58.4	55.2	56.4	60.0
		2.	51.6	61.2	60.6	58.0	62.0	62.2
IV	A	1.	58.6	52.8	61.0	58.0	59.2	53.4
		2.	58.4	50.4	55.4	59.2	57.4	52.4
	B	1.	65.4	59.8	57.4	64.8	61.8	57.2
		2.	62.4	56.0	56.2	62.6	58.2	56.0
IVF	A	1.	70.6	69.4	75.2	72.6	71.2	62.8
		2.	71.2	68.6	71.4	66.6	71.2	62.2
	B	1.	68.0	65.8	72.4	67.8	67.6	58.0
		2.	64.4	64.2	69.8	65.4	61.4	57.2

* Missing values estimated by formulae:-

$$I = \frac{bB + vV - G}{(b-1)\ (v-1)}$$

APPENDIX V (continued)

Block No.	Sampling Position	Duplicate No.	PR	CK	CH	WC	RC	BG
V	A	1.	70.8	65.8	67.2	64.4	65.8	60.2
		2.	67.2	60.2	62.0	61.0	62.8	60.8
	B	1.	70.2	60.2	69.8	62.4	67.2	64.8
		2.	72.6	61.2	68.6	63.0	66.2	60.8
VF	A	1.	58.0	60.2	54.6	51.0	48.8	44.2
		2.	55.8	58.0	61.0	56.8	53.6	48.4
	B	1.	65.6	68.8	68.4	49.4	64.2	56.8
		2.	63.6	67.2	64.6	60.4	63.2	53.0
Total			2563.6	2421.8	2500.2	2425.0	2415.2	2263.8
Mean			64.1	60.5	62.5	60.6	60.3	56.6

2. % 1-3 mm. air dry soil retained on a 0.251 mm. sieve.

Block No.	Sampling Position	Duplicate No.	PR	CK	CH	WC	RC	BG
I	A	1.	71.50	77.50	71.00	68.75	71.50	71.50
		2.	72.50	75.00	71.50	69.50	71.50	72.75
	B	1.	75.50	75.00	75.00	72.00	71.50	70.00
		2.	77.00	75.50	77.00	74.00	73.50	70.75
IF	A	1.	75.00	75.25	78.50	73.75*	73.25	72.25
		2.	74.75	74.50	76.00	73.75*	72.00	71.50
	B	1.	76.50*	72.25	79.00	73.50	75.25	71.00
		2.	76.75*	73.75	78.00	75.50	75.25	71.25
II	A	1.	72.75	71.00	70.00	71.75	72.50	71.75
		2.	74.25	74.00	72.75	71.50	74.75	73.50
	B	1.	74.00	70.00	73.50	75.25	72.50	72.50
		2.	74.00	74.50	74.00	72.50	74.25	72.75
IIF	A	1.	77.50	68.50	70.00	72.25	71.75	70.00
		2.	76.25	75.00	72.00	73.00	73.50	70.25
	B	1.	74.50	72.50	70.00	70.00	76.50	73.50
		2.	74.50	72.50	72.25	69.25	74.75	72.25
III	A	1.	78.50	74.50	69.75	71.50	72.00	73.50
		2.	75.75	75.00	71.25	77.50	72.50	73.25
	B	1.	74.75	71.00	73.50	75.25	71.00	73.00
		2.	74.75	72.75	73.25	73.00	72.75	73.25
Total			1501.00	1470.00	1468.25	1453.50	1462.50	1440.50

* Missing values estimated by formulae :-

$$\frac{bB + vV - G}{(b-1)\ (v-1)}$$

APPENDIX V (continued)

(b) B Plots

% 3-6 mm. air dry soil retained on a 1.676 mm. sieve.

Block No.		KR	PR	IT	CH	CK	WC	RC	BG
0"-2"	1.	77.6	45.4	43.4	52.0	46.2	46.6	44.6	27.0
	2.	73.2	50.2	42.4	55.4	42.8	43.4	44.0	34.6
	3.	81.8	39.0	48.4	46.4	40.0	42.0	36.0	22.6
	4.	76.2	42.2	50.8	52.0	44.6	45.2	42.0	27.2
	5.	65.2	51.0	55.0	45.0	36.8	47.4	42.8	31.4
	6.	87.0	47.4	58.6	54.8	40.4	53.6	55.6	29.6
	7.	76.8	52.2	50.2	56.2	45.6	61.8	43.2	29.2
	8.	86.6	55.8	52.6	64.0	57.2	60.0	61.4	42.8
2"-4"	1.	84.2	34.4	33.8	40.8	33.2	29.2	36.0	21.0
	2.	70.0	29.6	39.0	42.8	27.6	29.2	32.2	22.6
	3.	57.4	31.8	41.4	36.4	34.4	31.4	30.6	20.8
	4.	49.6	34.0	48.2	47.2	32.8	36.0	38.6	26.2
	5.	45.4	43.8	52.6	34.8	28.8	34.4	38.4	31.8
	6.	83.2	37.6	43.4	45.2	33.8	41.8	43.6	27.2
	7.	67.8	46.6	41.4	43.6	31.2	44.0	34.6	24.6
	8.	78.0	56.0	38.0	62.2	50.0	48.0	49.2	38.2
Total 0"-4"		1160.0	697.0	739.2	778.8	625.4	694.0	672.8	456.8
Mean		72.50	43.56	46.20	48.68	39.09	43.38	42.05	28.55

APPENDIX V (continued)

II. Eight Month Samples.

(a) A Plots. Main Treatment Comparisons.

Block No	Sampling Position	PR	CK	CH	WC	RC	BG
I	A	79.8	83.0	76.4	73.2	76.2	62.8
	B	81.6	79.6	81.2	74.6	74.0	55.0
IF	A	72.8	77.0	78.8	78.8	76.8	57.0
	B	76.4	79.4	77.6	73.6	66.8	58.8
II	A	74.4	77.2	79.6	76.4	73.4	54.6
	B	66.6	78.8	80.0	74.6	78.8	61.0
IIF	A	80.4	74.0	80.8	74.0	72.8	56.6
	B	80.6	81.2	81.6	72.4	71.4	59.2
III	A	76.6	73.6	81.0	78.4	74.6	70.6
	B	72.4	77.2	77.8	75.2	73.2	62.0
IIIF	A	76.0	77.8	77.8	72.4	63.8	57.6
	B	77.6	76.4	78.8	71.0	61.0	55.2
IV	A	68.2	69.2	70.6	77.4	69.0	62.8
	B	74.2	71.8	73.6	74.8	68.0	61.0
IVF	A	83.4	80.4	85.4	82.4	76.8	66.8
	B	85.2	80.6	83.8	78.2	80.4	67.8
V	A	79.0	78.2	85.0	72.6	73.6	62.6
	B	81.0	83.4	86.6	75.0	76.0	61.2
VF	A	72.6	75.0	71.8	66.2	70.0	61.4
	B	80.8	81.2	83.2	72.8	76.6	61.2
Total		1539.6	1555.0	1591.4	1494.0	1453.2	1215.2
Mean		76.98	77.75	79.57	74.70	72.66	60.76

APPENDIX V (continued)

(b) B Plots. Comparison of Sieving Times.

Block No.	Sieving Time.	PR	CK	CH	WC	RC	BG
IF	3	78.0	89.4	93.6	79.2	79.0	63.4
	5	76.4	81.2	77.8	77.8	71.2	54.4
	15	63.2	70.4	67.8	62.8	63.8	45.6
	30	56.2	67.4	59.4	60.0	57.6	40.6
II	3	74.2	86.0	-	77.6	76.2	67.2
	5	73.8	76.8	80.6	78.6	72.2	61.2
	15	63.0	66.4	67.4	63.2	61.0	49.0
	30	54.4	55.0	59.0	58.0	58.2	45.0
IIF	3	84.8	83.8	96.0	77.2	78.2	65.6
	5	78.2	76.6	79.4	70.4	74.0	57.0
	15	71.0	66.8	67.4	63.2	58.2	44.4
	30	60.6	58.4	62.8	51.2	56.4	39.8
III	3	81.6	80.8	83.8	83.6	78.0	78.8
	5	77.2	73.8	81.4	76.8	70.4	65.8
	15	64.2	61.2	67.0	64.8	60.2	48.0
	30	51.2	61.2	57.4	53.6	45.8	44.4
IIIF	3	82.4	82.4	82.0	82.6	77.2	63.4
	5	79.2	78.4	79.0	73.4	65.4	57.2
	15	63.8	65.0	65.6	60.8	52.0	45.4
	30	55.4	51.2	56.2	47.4	43.2	32.2
IV	3	73.0	74.8	79.8	74.6	66.0	57.8
	5	69.2	65.2	73.4	68.8	63.6	51.4
	15	57.2	53.8	55.8	60.2	55.2	41.2
	30	53.4	46.6	51.8	53.8	48.2	34.6
V	3	87.8	89.2	90.4	84.8	82.2	70.4
	5	82.6	83.0	86.6	76.8	75.4	64.2
	15	68.2	72.2	75.0	64.2	59.2	45.4
	30	60.6	62.6	67.2	48.8	49.2	37.2

(c) B Plots. Main Treatment Comparisons at 3 Depths.

Depth	Block	PR	CK	CH	WC	RC	BG	KR	IT
0"-2"	I	69.3	73.7	75.0	68.3	66.0	60.3	93.0	67.3
	II	73.3	70.6	75.6	63.7	57.3	65.3	91.0	69.7
	III	63.3	78.0	67.3	70.6*	71.3	73.0	67.3	78.8
	IV	81.3	*72.3	78.0	80.7	79.7	73.7	94.0	82.7
	V	75.0	81.7	79.0	77.7	71.0	68.0	91.3	79.7
	VI	71.7	77.7	76.0	78.0	78.0	66.0	88.7	79.7
	VII	77.3	69.3	74.7	71.0	79.0	73.0	92.0	72.0
	VIII	69.3	67.0	76.3	87.0	80.0	66.7	92.3	76.8
2"-4"	I	52.7	55.7	66.7	57.0	60.3	40.0	84.7	57.0
	II	54.3	60.0	69.7	56.3	45.7	56.0	87.0	67.3
	III	52.7	64.0	61.0	58.3	66.0	53.3	90.0	62.0
	IV	62.7	68.7	76.3	68.7	76.7	67.0	83.7	66.7
	V	67.7	72.0	62.3	68.3	72.0	59.3	90.3	66.7
	VI	63.3	68.7	71.3	65.7	67.3	61.7	86.0	65.0
	VII	62.3	59.0	68.3	62.0	65.3	61.3	89.3	60.7
	VIII	62.0	66.0	77.3	75.7	73.7	58.3	92.3	57.3
4"-6"	I	45.0	67.3	69.7	53.7	67.0	43.7	71.0	57.3
	II	61.0	44.7	65.3	49.0	55.0	45.7	78.5	77.0
	III	58.7	54.3	54.0	58.3	65.7	71.0	89.3	52.3
	IV	63.0	75.0	80.7	69.7	72.0	47.7	59.3	67.0
	V	57.0	64.3	55.0	52.7	65.7	61.3	76.7	67.0
	VI	59.7	60.0	82.3	71.7	65.3	51.0	75.7	68.0
	VII	55.3	64.0	84.0	62.0	74.0	62.0	74.3	54.7
	VIII	63.0	68.0	82.0	64.7	76.0	65.0	72.7	61.0
Grand Total		1520.9	1602.0	1727.8	1590.8	1650.0	1450.3	2010.4	1613.7
Mean		63.4	66.7	72.0	66.3	68.8	60.4	83.8	67.2

* Supplied by missing plot formula.

APPENDIX V (continued)

(d) B Plots. Sampled for Root & Structure Determinations. (Two depths used for structure).

Percentage Oven-dried soil retained on a 1.676 mm. sieve (3-6 mm. size fraction) or 0.251 mm. sieve (1-3 mm. size fraction).

Depth	Block No.	Size Fraction of Dry sieved soil.	CH	CK	IT	PR
0"-2"	I	3-6	63.4	57.0	67.7	57.1
		1-3	71.2*	73.6	75.6	73.6
	II	3-6	70.1	72.4	67.3	64.3
		1-3	72.0	77.2	77.6	74.0
	III	3-6	64.8	59.9	71.5	62.3
		1-3	75.2	75.6	79.2	76.4
	IV	3-6	72.5	62.3	77.9	61.4
		1-3	78.1	78.8	84.8	75.6
	V	3-6	68.4	60.2	83.2	74.9
		1-3	72.4	76.4	84.8	80.4
	VI	3-6	64.4	57.6	63.4	62.9
		1-3	74.4	78.0	78.8	74.8
	VII	3-6	62.8	69.9	66.0	66.2
		1-3	73.2	79.6	79.6	78.8
	VIII	3-6	73.0	56.7	60.3	64.6
		1-3	82.1	78.8	79.2	79.2
4"-6"	I	3-6	74.0	60.1	49.7	53.7
		1-3	68.4	70.6	67.6	69.2
	II	3-6	46.8	52.8	64.6	52.6
		1-3	58.8	73.6	69.2	69.2
	III	3-6	61.5	57.3	66.3	64.0
		1-3	68.0	69.2	75.2	74.4
	IV	3-6	69.8	53.0	65.7	45.7
		1-3	74.4	76.8	76.4	66.4
	V	3-6	44.5	62.8	60.6	55.1
		1-3	59.2	77.2	72.8	67.8*
	VI	3-6	52.0	61.5	52.9	61.4
		1-3	70.4	76.0	75.9	71.6
	VII	3-6	79.3	51.5	59.4	50.6
		1-3	81.0	75.2	74.8	73.6
	VIII	3-6	68.0	67.5	53.1	52.0
		1-3	72.8	75.6	72.0	69.6

* Supplied by missing plot formulae.

APPENDIX V (continued)

III. Twelve Month Samples

(a) A Plots. Main Treatment Comparisons at Three Depths.

Percentage 3-6 mm. air-dry soil retained on a 1.676 mm. sieve. Transformed to angles.

Depth	Block No.	Sampling Position	PR	CK	CH	WC	RC	BG
0"-2"	I	A	74.3	74.3	66.5	63.4	64.6	59.4
		B	78.9	74.8	77.0	71.2	76.3	66.3
	IF	A	68.0	69.1	72.0	66.3	54.0	51.3
		B	75.8	74.4	76.4	70.2	66.3	58.1
	II	A	75.6	71.6	63.9	69.6	66.7	57.8
		B	69.1	74.3	66.1	66.5	62.8	51.8
	IIF	A	72.2	71.4	71.1	68.0	67.1	60.8
		B	77.6	72.6	73.1	69.0	69.0	66.2
	III	A	75.4	75.4	72.6	72.8	66.9	66.5
		B	74.3	75.1	77.1	75.1	67.7	64.2
	IIIF	A	73.9	66.0	70.4	68.2	67.5	61.2
		B	76.3	73.5	74.1	71.4	63.9	65.3
	IV	A	72.3	69.0	61.8	73.3	63.6	60.7
		B	73.5	72.6	73.1	73.3	59.7	65.1
	IVF	A	75.8	73.7	75.6	75.8	69.3	67.9
		B	75.4	74.8	76.2	76.1	73.9	65.0
	V	A	74.6	75.5	73.7	69.8	67.2	53.3
		B	76.6	78.9	77.1	73.3	73.7	63.1
	VF	A	71.0	71.6	65.4	69.6	67.1	58.3
		B	78.0	73.5	76.4	74.3	75.6	67.2
2"-4"	I	A	73.3	71.6	70.4	62.5	56.9	57.2
		B	76.1	75.4	74.1	71.8	70.0	67.9
	IF	A	67.7	69.0	72.0	64.3	51.9	48.0
		B	73.3	72.2	74.8	68.4	61.7	52.3
	II	A	69.5	75.4	70.4	64.6	61.6	55.3
		B	68.2	72.6	71.0	55.8	58.2	53.3
	IIF	A	70.0	69.3	70.6	63.7	51.4	54.3
		B	76.6	73.3	72.0	62.8	59.3	64.2
	III	A	72.2	71.6	72.2	66.5	60.5	59.4
		B	67.7	75.4	75.8	65.6	61.3	61.1
	IIIF	A	68.4	69.1	70.6	66.7	62.9	57.2
		B	71.6	70.6	72.3	66.9	61.8	57.1
	IV	A	66.5	63.6	64.0	67.7	58.1	56.1
		B	69.6	67.7	70.0	65.0	56.0	59.2

APPENDIX V (continued)

Depth	Block No.	Sampling Position	PR	CK	CH	WC	RC	BG
2"–4"	IVF	A	70.2	73.1	74.8	69.0	67.1	59.8
		B	74.1	75.1	76.6	73.1	69.1	61.8
	V	A	71.4	74.1	72.6	65.3	59.9	51.3
		B	76.3	78.9	74.6	64.8	65.1	59.7
	VF	A	69.3	69.1	68.4	63.2	60.9	54.8
		B	75.1	71.6	76.3	72.2	71.6	61.5
4"–6"	I	A	68.6	64.0	69.3	61.5	61.5	60.7
		B	73.3	75.1	72.2	67.2	69.1	63.4
	IF	A	67.2	64.8	69.8	62.7	54.6	48.3
		B	73.5	71.6	73.7	65.0	57.5	50.6
	II	A	65.3	73.9	68.8	65.0	56.2	52.1
		B	65.4	73.3	68.2	62.1	60.8	57.6
	IIF	A	72.0	69.8	71.8	62.7	51.9	56.5
		B	71.4	71.6	75.4	61.8	59.9	63.2
	III	A	69.1	64.8	71.2	64.2	56.4	54.6
		B	69.6	74.6	72.0	59.8	57.5	55.6
	IIIF	A	62.0	66.2	63.7	59.2	60.1	49.4
		B	68.2	62.9	68.2	62.8	58.9	60.5
	IV	A	63.7	64.0	60.8	71.0	53.9	60.8
		B	65.6	65.3	65.9	67.1	53.9	59.5
	IVF	A	67.5	71.6	73.7	68.0	67.2	60.7
		B	74.6	72.2	76.1	71.6	66.7	61.9
	V	A	65.7	71.6	72.8	60.8	58.9	52.7
		B	75.1	74.6	71.0	66.9	68.4	59.2
	VF	A	65.4	68.8	66.9	63.7	60.8	53.0
		B	72.6	74.6	73.9	70.4	69.6	56.7
TOTAL			4290.8	4295.6	4288.2	4029.6	3772.0	3518.0
MEAN			71.5	71.6	71.5	67.2	62.9	58.7

(b) A Plots.

Percentage of unscreened sample retained on a 1.676 mm. sieve.

Depth	Block No.	PR	CK	CH	WC	RC	BG
0"-2"	I	48.2	35.3	29.8	41.5	41.3	35.7
	IF	43.6	38.2	30.6	47.2	34.6	30.1
	II	46.0	36.5	34.3	41.0	37.1	26.9
	III	49.2	35.9	40.1	51.7	41.9	38.3
	IIIF	46.9	38.1	33.3	47.6	34.6	36.0
	IV	46.2	37.8	25.8	47.8	36.2	41.3
	IVF	45.9	38.7	30.7	46.9	47.5	38.5
	V	43.8	45.5	31.0	46.2	45.1	35.6
	VF	47.3	40.4	32.4	47.8	46.0	38.9
2"-4"	I	45.1	43.7	35.4	38.1	34.3	38.9
	IF	47.9	37.8	42.3	38.9	27.8	26.8
	II	44.4	36.7	38.1	29.2	39.8	23.9
	III	35.1	43.1	45.1	36.4	40.4	34.3
	IIIF	44.9	42.5	41.9	40.3	31.1	30.3
	IV	39.6	35.8	36.7	37.2	35.9	33.1
	IVF	42.7	43.6	41.0	41.5	38.3	37.5
	V	49.1	49.8	38.9	39.3	34.8	31.0
	VF	44.8	35.5	37.8	40.8	39.0	38.8
4"-6"	I	45.5	50.9	36.3	43.3	43.4	33.8
	IF	44.4	39.4	37.7	37.1	36.1	39.0
	II	41.7	42.0	39.8	41.9	36.5	32.4
	III	42.7	43.2	44.4	34.2	37.0	34.1
	IIIF	41.3	39.1	42.7	41.2	32.5	33.7
	IV	42.5	42.1	39.8	40.0	33.7	37.1
	IVF	49.1	38.9	48.8	41.7	45.0	40.4
	V	51.9	47.9	41.1	40.4	39.9	35.1
	VF	45.8	42.3	41.5	45.3	39.3	35.7
Total		1215.6	1100.5	1017.3	1123.9	1029.0	937.3
Mean		45.0	40.8	37.7	41.6	38.1	34.7

(c) A Plots.

Percentage of unscreened sample retained on a 0.251 mm. sieve.

Depth	Block No.	PR	CK	CH	WC	RC	BG
0"–2"	I	77.5	75.6	65.1	74.5	77.1	70.3
	IF	77.5	74.3	69.6	79.7	78.2	71.7
	II	77.9	74.7	71.7	79.9	77.0	67.4
	III	78.8	71.1	72.0	80.8	77.7	72.4
	IIIF	79.3	74.3	69.6	78.9	74.3	70.9
	IV	77.9	74.4	65.4	79.2	74.1	73.6
	IVF	76.8	73.8	66.2	76.7	77.7	74.1
	V	75.3	75.5	68.6	77.3	78.7	72.1
	VF	76.8	75.5	71.3	77.1	78.4	72.8
2"–4"	I	74.0	74.1	70.5	71.9	70.7	71.9
	IF	77.9	73.8	74.5	75.3	71.5	70.0
	II	76.2	70.9	74.0	69.4	76.7	65.5
	III	70.5	73.9	75.6	73.1	74.0	70.9
	IIIF	74.6	74.0	73.9	74.2	69.5	68.1
	IV	73.6	71.0	71.7	72.9	71.3	70.1
	IVF	75.2	74.9	72.9	74.4	72.3	74.1
	V	77.3	76.2	73.3	74.4	70.8	71.1
	VF	75.4	72.1	72.7	74.8	72.8	73.0
4"–6"	I	75.2	78.1	73.3	74.6	76.5	72.3
	IF	76.6	73.7	71.3	73.2	72.7	75.7
	II	74.5	74.1	74.1	76.6	73.4	70.9
	III	72.9	74.1	74.7	70.6	72.2	68.1
	IIIF	73.4	72.2	73.6	74.9	70.9	71.3
	IV	75.3	74.8	75.0	74.7	70.4	74.5
	IVF	78.1	72.3	77.5	74.8	76.5	77.8
	V	80.9	76.8	76.8	76.7	75.1	74.2
	VF	78.2	75.4	75.1	76.2	74.7	72.1
Total		2057.5	2001.3	1949.8	2036.5	2005.1	1936.9
Mean		76.2	74.1	72.2	75.4	74.3	71.7

APPENDIX V (continued)

(d) A Plots.

Percentage of 3-6 mm. size fraction in the whole soil.

Depth	Block No.	PR	CK	CH	WC	RC	BG
0"-2"	I	45.1	36.9	27.0	42.9	47.1	44.8
	IF	46.3	38.3	29.3	46.6	40.9	38.8
	II	49.5	38.6	28.1	54.3	37.8	45.1
	IIF	42.8	35.2	25.7	49.5	40.3	43.3
	III	39.6	40.0	36.7	52.7	49.0	49.3
	IIIF	46.7	37.0	27.6	45.8	48.2	46.9
	IV	45.1	38.4	31.6	50.5	49.8	47.2
	IVF	43.6	45.3	35.9	52.2	45.7	50.2
	V	45.4	39.9	37.0	50.7	47.6	45.5
	VF	44.1	37.9	22.8	46.6	44.6	49.6
2"-4"	I	51.5	45.9	37.6	46.4	39.7	47.2
	IF	43.3	44.4	35.3	41.6	39.2	41.9
	II	48.7	42.6	44.2	49.3	41.4	45.2
	IIF	42.4	40.3	36.7	45.0	34.4	42.5
	III	42.5	43.6	49.1	44.3	46.3	48.1
	IIIF	54.2	44.6	35.1	49.5	47.1	50.5
	IV	47.5	43.3	38.9	46.5	44.9	47.4
	IVF	47.4	47.9	47.6	44.6	39.8	51.1
	V	49.6	41.9	45.9	43.3	43.3	44.9
	VF	45.1	38.8	36.0	47.4	37.8	49.3
4"-6"	I	45.0	49.8	42.0	49.2	43.1	53.4
	IF	48.8	37.9	41.4	42.6	42.5	49.1
	II	49.0	47.9	49.0	47.2	48.4	43.7
	IIF	44.1	53.2	43.1	47.2	43.6	51.8
	III	40.8	46.9	50.3	42.1	49.7	47.3
	IIIF	50.6	46.7	40.9	50.0	48.0	47.3
	IV	47.8	44.6	44.1	50.3	50.5	50.6
	IVF	46.8	42.9	44.3	50.8	45.7	55.0
	V	51.2	47.1	43.5	43.5	46.2	51.3
	VF	45.7	46.7	37.0	49.2	40.3	54.0
Total		1390.2	1284.2	1143.6	1421.8	1322.5	1432.2
Mean		46.3	42.8	38.1	47.4	44.1	47.7

Table of Means of Grass Treatments

Depth	PR	CK	CH
0"-2"	44.82	38.75	30.17
2"-4"	47.22	43.23	40.64

0"-2" : For significance at the 5% (1%) level differences must exceed 3.19 (4.23).

2"-4" : For significance at the 5% (1%) level differences must exceed 3.74 (5.12).

4"-6" : Differences not significant.

APPENDIX V (continued)

IV. Twenty Month Samples

(a) A Plots. Main Treatment Comparisons at Three Depths.

Percentage oven-dried 3-6 mm. soil fraction retained on a 1.676 mm. sieve. (Transformed to Angles)

Depth	Block No.	PR	CK	CH	WC	RC	BG
0"-2"	I	72.5	72.2	70.0	74.3	71.9	68.0
	IF	73.3	74.0	72.2	71.6	72.2	68.6
	II	75.0	76.2	74.7	75.8	74.7	64.9
	IIF	72.2	72.5	74.7	72.2	73.3	64.9
	III	75.0	73.6	73.3	73.3	73.3	72.5
	IIIF	75.5	72.5	77.1	72.8	73.3	60.5
	IV	73.9	74.7	71.4	73.3	70.0	63.2
	IVF	75.5	76.2	74.7	75.0	71.9	68.9
	V	74.3	73.9	72.2	74.3	73.9	69.5
	VF	73.3	75.0	75.5	72.8	71.9	59.2
2"-4"	I	70.6	71.9	70.4	70.4	66.4	63.7
	IF	68.6	70.6	71.3	65.1	62.2	60.2
	II	72.8	73.6	73.6	71.3	69.7	57.2
	IIF	72.2	71.3	71.9	65.4	67.0	63.2
	III	72.2	72.2	69.7	68.0	65.7	67.5
	IIIF	75.0	69.5	73.3	67.8	67.5	59.8
	IV	69.5	70.9	68.0	70.0	55.7	62.9
	IVF	72.8	72.5	72.2	68.6	70.9	65.1
	V	72.5	69.1	73.3	69.5	73.3	68.0
	VF	69.7	71.9	72.5	66.5	68.6	54.8
4"-6"	I	69.7	67.5	69.6	67.5	64.4	62.0
	IF	69.5	68.0	73.3	58.5	50.4	59.5
	II	68.6	70.0	72.6	67.8	60.2	51.5
	IIF	69.1	71.3	72.2	63.4	62.5	63.9
	III	70.6	68.0	68.2	65.4	57.2	64.4
	IIIF	70.0	64.2	67.8	63.7	56.4	56.0
	IV	64.7	67.2	67.5	60.7	55.7	58.7
	IVF	69.1	71.6	69.5	63.9	67.8	63.9
	V	72.8	66.4	71.0	65.9	62.7	68.6
	VF	70.4	69.5	70.4	65.1	64.9	54.3
Total		2150.9	2138.0	2154.1	2059.6	1995.6	1885.4
Mean		71.60	71.27	71.80	68.65	66.52	62.85

APPENDIX V (continued)

(b) A Plots. Sampled at Three Depths. Preshaken.

Percentage oven-dried 3-6 mm. soil fraction retained on a 1.676 mm. sieve.

Depth	Block No.	PR	CK	CH	WC	RC	BG
0"-2"	I	87.3	80.7	81.0	88.0	82.3	65.7
	IF	87.3	84.0	86.0	84.0	85.3	76.3
	II	87.3	90.0	88.3	89.0	87.7	68.7
	IIF	85.7	82.7	86.0	82.0	81.3	66.0
	III	88.7	89.0	84.7	86.3	84.0	84.0
	IIIF	90.0	87.0	87.8	83.7	84.0	68.0
	IV	89.7	87.0	83.0	83.0	76.0	64.3
	IVF	86.7	88.0	87.7	83.3	86.0	75.0
	V	88.3	87.3	86.3	84.7	84.0	74.3
	VF	84.3	88.3	90.3	80.0	84.0	60.0
2"-4"	I	82.3	78.7	82.7	79.7	74.0	66.3
	IF	78.0	78.0	82.7	70.0	66.3	62.7
	II	83.3	83.7	86.3	79.0	71.7	59.3
	IIF	83.7	82.3	81.3	70.7	73.3	59.7
	III	83.7	83.7	79.7	75.7	70.7	70.7
	IIIF	82.3	80.0	85.0	74.3	68.3	57.7
	IV	80.0	79.7	75.3	71.7	54.3	58.7
	IVF	84.0	84.0	82.3	77.7	75.3	71.3
	V	83.7	79.7	86.0	71.7	70.0	69.0
	VF	80.0	81.7	87.0	71.0	72.3	49.7
4"-6"	I	80.3	77.0	80.3	76.3	68.7	67.3
	IF	79.0	77.7	86.3	62.0	49.0	65.3
	II	77.3	79.7	80.7	69.3	59.3	50.7
	IIF	78.3	81.0	84.3	67.7	69.7	68.3
	III	80.7	78.0	79.3	73.3	54.3	66.3
	IIIF	75.3	71.3	75.7	66.3	54.0	57.0
	IV	75.3	77.7	74.7	59.7	57.3	62.3
	IVF	78.7	79.7	80.3	71.3	73.7	73.0
	V	84.3	75.3	83.1	69.3	61.0	70.0
	VF	79.3	79.3	82.7	69.0	68.7	48.0
Total		2484.8	2452.2	2496.8	2269.7	2146.5	1955.6
Mean		82.83	81.74	83.23	75.66	71.55	65.19

APPENDIX VI.

Root Determinations

I. Four Month Samples

(a) B Plots. Root weight in mgms. per 44.89 sq. cms. at two depths.

Depth	Block No.	PR	CK	CH	WC	RC	IR
0"-2"	1.	400	538	321	363	393	539
	2.	547	522	436	277	384	458
	3.	465	464	360	280	464	438
	4.	524	414	378	324	390	589
	5.	638	449	456	437	459	684
	6.	787	506	482	515	537	759
	7.	806	705	644	690	475	689
	8.	705	618	688	446	652	602
2"-4"	1.	178	150	118	103	155	187
	2.	265	194	158	91	141	295
	3.	198	219	154	127	127	201
	4.	222	148	188	108	149	157
	5.	263	183	197	135	161	269
	6.	286	233	210	177	171	325
	7.	394	303	235	189	171	200
	8.	287	268	239	178	261	276
Total		6965	5914	5264	4440	5090	6668

APPENDIX VI (continued)

(b) B Plots. Crown root numbers per 44.89 sq. cms.

Block No.	PR	CK	CH	WC	RC	IR
1.	261	413*	137	49	12	325
2.	265	401	175	45	13	178
3.	227	565	235	30	28	207
4.	200	366	300	40	16	313
5.	258	472	288	66	13	296
6.	405	270	311	36	15	426
7.	339	723	485	68	10	322
8.	354	295	315	27	18	166
Total	2309	3505	2246	361	125	2233

* Calculated from missing plot formulae (83)

(c) B Plots. Crown roots per tiller.

Block No.	PR	CK	CH	WC	RC	IR
1.	3.390	12.906	1.191	0.961	0.400	6.915
2.	3.786	8.184	1.357	0.833	0.317	4.944
3.	3.547	8.561	1.822	0.750	0.500	4.928
4.	3.846	8.512	1.485	0.909	0.421	5.906
5.	3.634	10.977	1.674	0.959	0.382	6.727
6.	4.355	10.000	1.312	1.000	0.405	8.520
7.	3.568	10.791	1.497	0.986	0.435	7.488
8.	6.556	10.536	1.886	0.844	0.563	8.300
Mean	4.085	10.058	1.528	0.905	0.428	6.716

(d) No. of tillers per sample of 44.89 sq. cms.

Block No.	PR	CK	CH	WC	RC	IR
1.	77	32	115	51	30	47
2.	70	49	127	54	41	36
3.	64	66	129	40	56	42
4.	52	43	202	44	38	53
5.	71	43	172	69	34	44
6.	93	27	237	36	37	50
7.	95	67	324	69	23	43
8.	54	28	167	32	32	20
Total	576	355	1473	395	291	335

(e) No. of worms per sample of 44.89 sq. cm.s

Block No.	PR	CK	CH	WC	RC	IR
1.	1	1	1	2	1	2
2.	3	2	2	2	2	0
3.	1	2	0	2	0	1
4.	0	3	0	0	0	1
5.	0	2	1	1	1	0
6.	1	0	0	1	0	1
7.	1	0	0	0	0	3
8.	0	1	0	1	1	1
Total	7	11	4	9	5	9

APPENDIX VI (continued)

II. Eight Month Samples.

(a) B Plots. Root weights in mgms. per 20.15 sq. cms. at the 2"-4" depth.

Block No.	PR	CK	CH	IT
1.	189	150	202	143
2.	123	170	135	175
3.	159	125	143	129
4.	146	138	148	134
5.	206	149	141	148
6.	143	155	143	132
7.	166	143	176	120
8.	108	118	177	126
Total	1240	1148	1265	1107

APPENDIX VI (continued)

III. Twelve Month Sample

(a) A Plots. Root weight in mgms. per 44.89 sq. cms. at three depths.

Depth	Block No.	PR	CK	CH	WC	RC (Fibrous Roots)	RC (Taproot)
0"-2"	I	1093	1059	1711	680	446	1873
	IF	1739	1453	1281	485	383	2174
	II	1147	956	1133	530	261	701
	IIF	1335	1164	1023	382	385	813
	III	876	729	1888	635	393	640
	IIIF	918	1082	1338	374	481	474
	IV	1071	848	1105	779	455	445
	IVF	870	837	1268	550	339	405
	V	1049	922	1451	663	350	1704
	VF	1249	726	1919	421	545	1253
2"-4"	I	396	240	364	149	286	688
	IF	498	245	414	195	282	767
	II	420	381	453	159	129	283
	IIF	301	374	399	126	160	374
	III	302	321	506	252	107	72
	IIIF	356	291	479	100	157	68
	IV	341	241	395	165	90	-
	IVF	261	228	308	214	120	84
	V	350	250	348	151	287	487
	VF	233	225	481	119	212	339
4"-6"	I	297	190	324	87	254	220
	IF	304	196	288	89	268	274
	II	272	270	290	102	212	81
	IIF	272	244	269	131	93	-
	III	255	249	419	139	107	9
	IIIF	234	168	430	109	134	42
	IV	226	187	250	128	76	-
	IVF	192	149	300	190	142	41
	V	198	190	289	116	174	99
	VF	169	216	319	63	109	-
Total		17224	14631	21442	8282	7437	14453

APPENDIX VI (continued)

IV. Twenty Month Samples.

(a) A Plots. Root weight in mgms. per 20.15 sq. cms. at the 2"-4" depth.

Block No.	PR	CK	CH	WC	RC (Fibrous)	RC (Taproot)	BG
I	177	128	306	65	62	92	16
IF	181	158	215	118	58	340	13
II	155	112	314	48	100	105	21
IIF	172	168	243	82	62	179	47
III	152	139	280	101	70	201	49
IIIF	228	131	358	155	88	186	41
IV	184	139	233	126	153	324	28
IVF	155	153	288	81	88	102	40
V	192	120	331	68	403	388	29
VF	225	124	324	139	81	-	38
Total	1821	1372	2892	983	1165	1917	322

APPENDIX VII. Rate of oxygen absorption per hour measured in microlitres per gm. of dry soil to which grass and clover roots had been previously added.

Treatment	Control	PR	CK	CH	WC(new)	RC(new)	WC	RC	PR(6 gms)	CH(6 gms)
11 Nov. 1953	7.28	8.57	-	12.28	-	-	-	-	-	-
	7.11	9.32	11.60	19.82	-	-	-	-	-	-
	7.03	10.95	8.89	11.11						
12 Nov. 1953	6.65	-	8.07	-	15.03	19.70	-	-	-	-
	7.27	-	10.79	-	42.82	30.58	-	-	-	-
	7.52	-	9.18	-	24.06	23.95	-	-	-	-
18 Nov. 1953	2.21	5.61	5.12	7.30	-	-	-	-	-	-
	2.71	4.79	3.76	6.99	-	-	-	-	-	-
	2.95	5.78	4.73	6.38	-	-	-	-	-	-
19 Nov. 1953	2.54	-	-	-	14.50	-	6.22	15.71	-	-
	2.56	-	-	-	12.64	-	8.19	6.59	-	-
	2.45	-	-	-	16.39	-	12.37	7.42	-	-
3 Dec. 1953	1.42	1.73	1.47	1.74	-	-	-	-	-	-
	2.20	2.52	1.88	2.21	-	-	-	-	-	-
	1.81	2.00	2.28	2.60	-	-	-	-	-	-
4 Dec. 1953	-	-	-	-	-	-	2.05	2.29	2.30	3.03
	-	-	-	-	-	-	2.50	2.40	1.49	3.22
	-	-	-	-	-	-	2.23	2.19	2.34	2.87
5 Jan. 1954	1.40	1.93	2.79	2.01	-	-	-	-	-	-
	1.03	2.22	2.63	2.12	-	-	-	-	-	-
	1.12	2.94	2.59	2.57	-	-	-	-	-	-

APPENDIX VIII

Structure of soils from pot experiment.

(a) 30 days after addition of roots.

Treatment	Sample I	Sample II	Sample III	Sample IV
Control	60.8	60.4	61.2	62.4
WC (new)*	64.4	65.6	76.8	75.2
(WC	65.2	66.8	78.0	75.2
RC (new)	72.0	73.6	79.2	79.6
RC (tap root)	76.0	76.0	79.2	80.0
RC (fibrous)	69.6	64.8	68.4	65.2
CH (new)	62.8	61.2	73.2	70.4
CH	68.0	62.0	67.2	66.4
CH (6 gms)**	72.4	67.6	73.6	74.8
CK (new)	70.0	66.8	70.0	68.4
CK	63.2	64.0	70.4	68.8
PR (new)	67.2	68.8	74.8	70.8
PR	64.8	59.6	68.0	66.0
PR (6 gms)	64.4	65.2	71.6	72.0
IT (new)	66.8	65.6	75.6	73.6
Control	60.8	60.4	68.0	64.4

(b) 70 days after addition of roots.

Treatment	Sample I	Sample II	Sample II	Sample IV
Control	63.2	64.0	60.0	59.6
WC (new)*	75.6	74.8	72.8	76.0
WC	76.4	72.0	74.4	72.4
RC (new)	77.2	73.2	72.0	76.8
RC (tap root)	78.8	76.8	74.4	73.6
RC	73.6	70.0	70.8	72.8
RC (tap root, 6 gms.)**	90.0	88.4	88.8	87.6
CH (new)	72.0	69.6	73.2	72.0
CH	66.0	69.6	74.0	72.8
CH (6 gms)	80.0	78.8	80.0	78.0
CK (new)	75.6	75.2	74.0	74.4
CK	65.6	66.4	66.8	69.6
CK (6 gms)	78.8	75.6	76.8	74.4
PR (new)	76.8	77.6	72.4	76.0
PR	66.8	68.0	69.2	75.2
PR (6 gms)	76.8	78.4	74.8	74.4
IT (new)	72.0	74.0	74.4	76.0

* "New" refers to roots from 4 month old plants. Remainder are from 12 month old plants.

** "6 gms" refers to the amount of roots added to each pot. The remaining pots had 3 gms.

APPENDIX IX.

Grass Grub and Earthworm Counts.

In the autumn following the final soil sampling grass grub (Odontria zealandica) made a noticeable appearance on some of the plots. White clover plots which had been vigorous in their growth up to this time were particularly hard hit and by the end of April were showing no growth and the turf could be rolled up like a carpet.

It was decided therefore to make a count of the grubs present at this time and also to sample some of the species with a view to finding out whether the pulverising effect of the grass grub would be recorded by the wet sieving apparatus. This was done and the following table sets out the number of grubs obtained from an area 1 foot square and nine inches deep on five of the replications.

Block No.	BG	CK	PR	CH	RC	WC	Total
I	33	62	63	71	48	56	333
II	3	28	54	47	47	49	228
IIF	22	1	16	21	18	36	114
III	59	57	43	62	52	33	306
IIIF	54	26	18	10	44	73	225
Total	171	174	194	211	209	247	1206

Analysis of variance showed that the differences between species were not significant, many more samplings were required to give significance and time was not available, to proceed further with this.

The heaviest infestation was in the white clover plots where an average of 49 grubs per square foot were found. The mean weight of these grubs was 162 mgms. On this basis these plots were carrying a weight of approximately 7 cwt. of grass grubs per acre under the ground, a weight somewhat similar to what can be carried above ground in terms of sheep or cattle on a good pasture.

Samples for wet sieving have been air dried and stored in sealed bottles and it is intended that these will be analysed when opportunity offers.

At the same time as the counts on grass grubs were taken, the number of worms present per square foot were recorded and these appear in the following table.

Block No.	BG	CH	CK	RC	WC	PR	Total
I	5	8	12	15	28	22	90
II	15	9	19	17	35	23	118
IIF	5	9	13	19	14	28	88
III	18	1	12	22	38	29	120
IIIF	7	26	20	6	36	28	123
Total	50	53	76	79	151	130	539

Analysis of variance showed that white clover and perennial ryegrass were both highly significantly superior in worm numbers than the other plots between which there was no difference.

There was considerable variation in worm weight, but on the basis of the mean weight of 0.44 gms, the weight of worms per acre in the white clover plots was just over 11 cwt. This is low compared with Sears* figures of up to 20.5 cwt per acre on very high producing alluvial silt.

* Sears P.D. 1953. N.Z. Journ. Sc. Tech. Supp. 1, 42 - 52.

APPENDIX X.

Original Structure in Soils of B Plots

Percentage of 3-6 mm. soil fraction retained on a 1.676 mm. sieve.

Replicate	0"-2"	2"-4"	0"-4"
A	42.4	35.4	38.9
B	36.8	28.0	32.4
C	33.2	35.8	34.5
D	34.6	31.2	32.9
Mean	36.7	32.6	34.7