A PRELIMINARY INVESTIGATION INTO THE ROOT SYSTEMS OF PERENNIAL RYEGRASS (LOLIUM PERENNE) AND WHITE CLOVER (TRIFOLIUM REPENS) USING A PRESCRIBED SAMPLING METHOD FOR THE STUDY.

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C O N T E N T S.

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A. INTRODUCTION:

"The roots of plants are the least known,
least understood and least appreciated
part of the plant."

Weaver and Bruner.

The fundamental importance of an extensive, well developed and healthy root system cannot be over emphasised. It must hold the plant firmly in the ground, provide a large effective absorptive area through which ample nutrients will become available for growth, and, by penetrating deeply, or by building up reserves, it must protect the plant against the exigencies of a dry season.

The study of the roots then, important as they are, would appear to have been unduly neglected when one considers the amount of research carried out using as a basis some above ground feature of the plant. In this connection W.F. Loehwing (1) may be quoted - "As one surveys the monumental literature dealing with crop production, the small fraction thereof devoted to roots and the absorption processes seems entirely out of proportion to their importance".

This state of affairs may emanate from the failure to admit the possibilities of investigations of the roots or may be due to the difficulty of studying them, but whatever the cause it is very noticeable in the case of many of our pasture plants. These have been the objects of intensive breeding and selection

based on their ability to produce foliage and this work has affected a marked and creditable improvement in the last few years.

An examination of the present accepted methods of root study reveals that they are usually slow, tedious and expensive. Weaver (2) used a method wherein a large hole is excavated adjacent to the plant to be studied and each root is laboriously traced out by picking the soil away. Pavlychenko (3) has used a method which involves the removal of large blocks of soil which have to be hoisted from the ground. These methods, while being suitable for giving a picture of the nature of the root system of a particular species would be quite inadequate to show the effects of various treatments on that species. In the main such studies involve the use of single plants and/or the use of boxes of soil which immediately set up artificial conditions. Spragg (4) has used a system essentially similar to that described here wherein he digs out a small prism of soil and then trims it to a given size.

However, the method adopted here is very much simplified but is as yet untried and must be critically examined step by step and its value as a means of studying root behaviour under different experimental conditions ascertained. In view of this the investigation of several general points would appear to present wider scope for such preliminary exploration. Results which could be satisfactorily subjected to statistical analysis would naturally come later when a suitable technique has been

evolved and proven and the prerequisites of a statistically accurate experiment known.

Many problems would immediately present themselves for investigation following the evolution of a suitable technique. The effect on root development of placement of fertilizers, of the time of sowing down the pastures, of the various cultivation practices, are all points that could well be studied with a view to ascertaining the adequacy of existing systems of husbandry. Work done by Bertram (5) shows the depressing effect on the root system of allowing the water table to approach the surface of the soil, work by Jacques in N.Z. (6) demonstrates the detrimental results of too frequent grazing, while Bates (7) has amply illustrated the inhibiting effect of an acid soil. Similarly more work may bring to light new, or provide additional confirmation of known effects of mis-management.

The accumulation of a detailed knowledge of the roots themselves and the factors influencing their development might lead to much more important work being done. Some practical application may be found in the matter of soil erosion which is a very serious problem both from the individual farmer's point of view and perhaps more so from the national aspect.

Further, it is not impossible that a strain of grass may be evolved which is suited to dry or sandy areas by virtue of a root system which penetrates deeply or which is capable of storing considerable reserves or which in other ways allows the plant to continue growth or maintain itself under such adverse conditions.

While realising the value of root studies one must not lose sight of the fact that the ultimate test of a strain of grass is the amount of food material produced. Actually a high total production may not be so important as a lesser production with much of it at a period of normally low production or during a period of adverse conditions for growth. The point is, however, that only insofar as they increase the value of the species have root studies any practical application in this direction.

B. OBJECT OF THE WORK:

The primary object of this work was to study the root systems of Perennial Ryegrass and White Clover in pure and in mixed plots with different spacings of the plants.

At the outset it was hoped to replicate the plots in order to get results which could be statistically analysed. However, it was not known if sufficient samples could be dealt with in the time allotted, and furthermore it early became evident that the original number of plots could not be laid down without an undesirable lapse of time between completing the first and last plots. It was decided, therefore, to keep the investigation along more general lines and to defer any detailed statistical analysis until any weakness in the methods used had been determined and any faults in the technique found.

Thus the object of the work may be stated to be a preliminary study of the root systems of Perennial Ryegrass and White Clover using a prescribed sampling method for the study. It is preliminary since statistical accuracy is not aimed at and in addition the method investigation adopted may be found to have weaknesses of sufficient magnitude to invalidate any conclusions drawn from the results obtained.

The aims and objects of the experiment can be enumerated as follows :

(1) A comparison of the root development of Perennial Ryegrass and White Clover when growing in pure plots and in combination.

(2) Determination of the effect on roots of defoliating at weekly and two-weekly intervals.

(3) Consideration of the effect on roots of different spacing of the plants, i.e. 1" and 3".

(4) Consideration of the value of the technique used as a method of root study.

(5) Correlation of root development with production of leaf.

(6) Some observations on the occurence and influence of the nodules on White Clover.

(7) General observations.

C. METHOD OF THE EXPERIMENT:

I. General Description.

Two series of plots were laid down there being one series in which the plants were one inch apart and one in which they were three inches apart. Each series consisted of pure plots of Perennial Ryegrass, a Certified No.1 White Clover, and a certified permanent pasture White Clover, together with the combination of Perennial Ryegrass with each of the clovers. Cutting of these plots followed a regular sequence and was done at weekly and two-weekly intervals. (See Figs. 1 and 2).

Approximately once per month a sample was taken with a sampler devised by Jacques (8) from each plot, and transferred to the laboratory where the roots were washed free of soil, examined, and the weight of roots per sample determined. By means of these samples the condition of the root system in each plot was ascertained.

As a check to the plot results, pots were also used and these consisted of 12" glazed drain pipes sunk into the ground and filled with a sandy loam. Two series were planted with the various species and combinations as in the plots, and, similarly one pot of each was cut at weekly and one at two-weekly intervals. The two series of pots were duplicated and one lot lifted after four months and one lot after nine months. The pots were excavated and the roots washed free of soil, the root systems of certain plants examined intact and their weights determined. Comparison

could thus be made with the root behaviour as found in the plots.

II. The Plots:

a) Plan of the Plots:

The plan of the plots as originally intended is shown in Fig. 1, while the final plan as modified, for the reasons described, is shown in Fig. 2.

b) Laying Down the Plots:

Sowing the plots: The area on which the plots were sown had previously been in single plants of Cynosurus Cristatus and as these plants were regularly inter-cultivated the ground was in good order and clean. The area was dug over in the autumn and prepared for planting in the spring.

An area slightly larger than that intended for each plot was sown down with the appropriate seed with the intention of thinning the plants out to the required distance apart and to the correct number for the particular plot.

In the plots in which the plants were one inch apart the total area of each plot was 40" x 40" which, after allowing two rows for the edge effect gave a sampling area of 36" x 36".

In the case of the plots in which the plants were 3" apart 17 rows of 17 plants gave an area of 51" x 51" which, allowing two rows for edge effect, gave a sampling area of 36" x 36". In the mixed plots 18 rows were sown to give an equal number of rows of clover and ryegrass.

The seed used was as follows :

(i) A No.1 White Clover. (Abbreviation No.1 Clover).

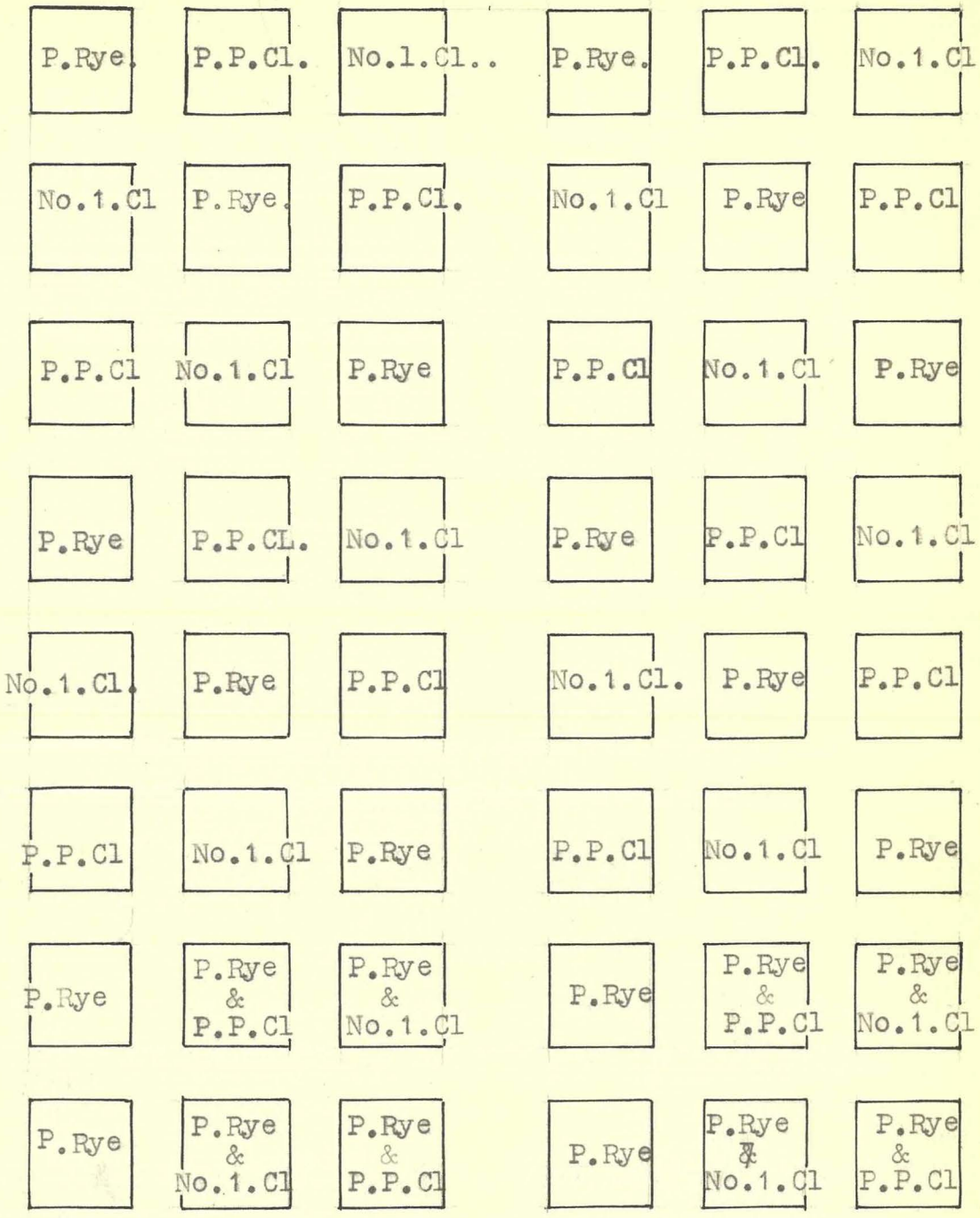

FIG. 1. Original plan of the plots.

Abbrev. P.Rye.... Perennial Ryegrass

No.1.Cl.. No.1. White Clover

P.P.Cl... P.P. White Clover

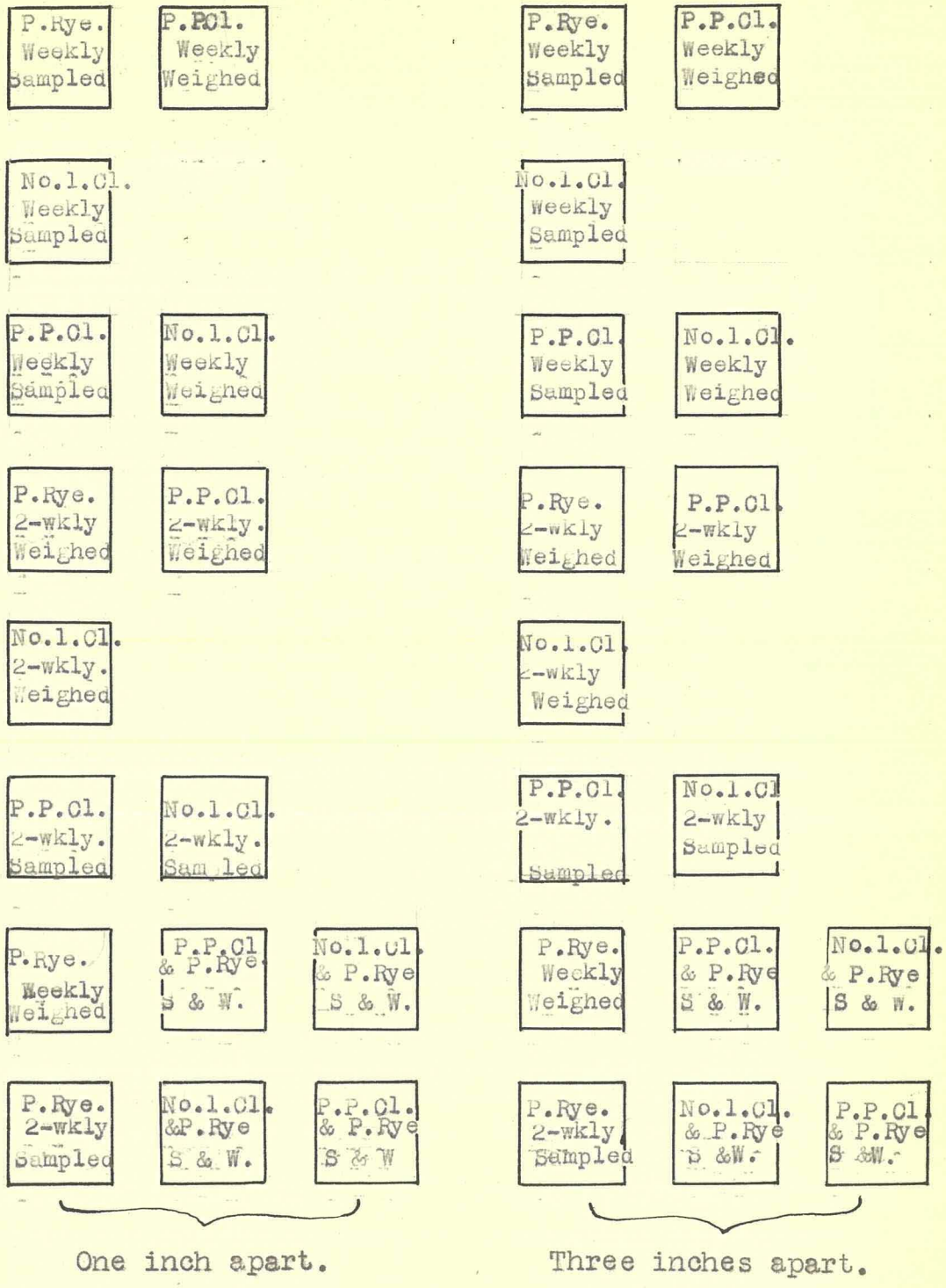

FIG. 2. Plan of the plots. (Final)

Abbreviations.

P.Rye.	Perennial Ryegrass
No.1.Cl.	No.1. White Clover.
P.P.Cl.	P.P. White Clover.
S & W.	Sampled and Weighed.

This seed ZM/117 was described as a very good Mother seed White clover as described by Levy and Gorman (10). The Seed Testing Station report shows that it has a very good HCN test, germination 82%, and purity 98.9%.

(ii) A Permanent Pasture White Clover (Abbreviation P.P. Clover). This seed ZP/2 as described by Levy and Gorman (10) is a No.2 White Clover or certified permanent pasture type. The Seed Testing report shows it to have a poor HCN test.* germination 95%, and purity 94.7%.

(iii) A Perennial Ryegrass. (Abbreviation P. Rye). This seed HB/343/AE was described as a certified permanent pasture ryegrass having a germination 97%, purity 99.7%.

All seed was sown on Sept. 24th. 1937. Before sowing a mixture of equal amounts of Sulphate of Ammonia and Superphosphate was broadcast and raked into the surface soil at the rate of 3 cwt. per acre.

Thinning the plants was commenced on Oct. 25th. 1937. It was soon found that thinning the plants out to one inch apart was not altogether satisfactory as few plants were in the correct place since the plants came up less evenly than was anticipated. The method adopted was to utilise such plants as were in place and to transplant to the spaces plants from the thicker patches.

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*N.B. Work done by Doak (11) indicates that the No.1 type used, since it has a very good HCN test, would be a particularly high production type while the P.P. Clover though a high production type as compared with one such as Kentish Wild White would be much inferior to the No.1 strain.

A square frame 60" x 60" made of 3 x 1" timber with holes drilled one inch apart on opposite sides was used for the thinning and transplanting. See Fig. 3. A cord knotted at 1" intervals was attached at each end to a peg, and, by inserting these pegs in the appropriate holes in the frame the position of each plant in the row was indicated by the knots on the cord. By shifting the pegs to the next hole on each side of the frame the position of each plant in the next row was indicated. This frame served a particularly useful purpose.

Effect of Transplanting: No effect on the Perennial Ryegrass was observed although it possibly induced branching and lateral root formation. No doubt after a time only a small proportion of the roots present would have been affected since new roots are continually developing. In the Clover, however, the main tap root was frequently observed to be bent into a U shape. This must have influenced root development but it can be assumed to have affected all the plots similarly and for purposes of comparison can be considered satisfactory. In a more critical trial it would be desirable to obviate transplanting.

With regard to the mixed plots it may have had some bearing on relatively poor establishment of the clover though it is likely that other more important factors were operating. In the 1" apart mixed plots the Clover, for all practical purposes failed to develop, and, while this may be a true indication of the state of affairs that would normally occur where the species are close together it may be attributed to the method adopted

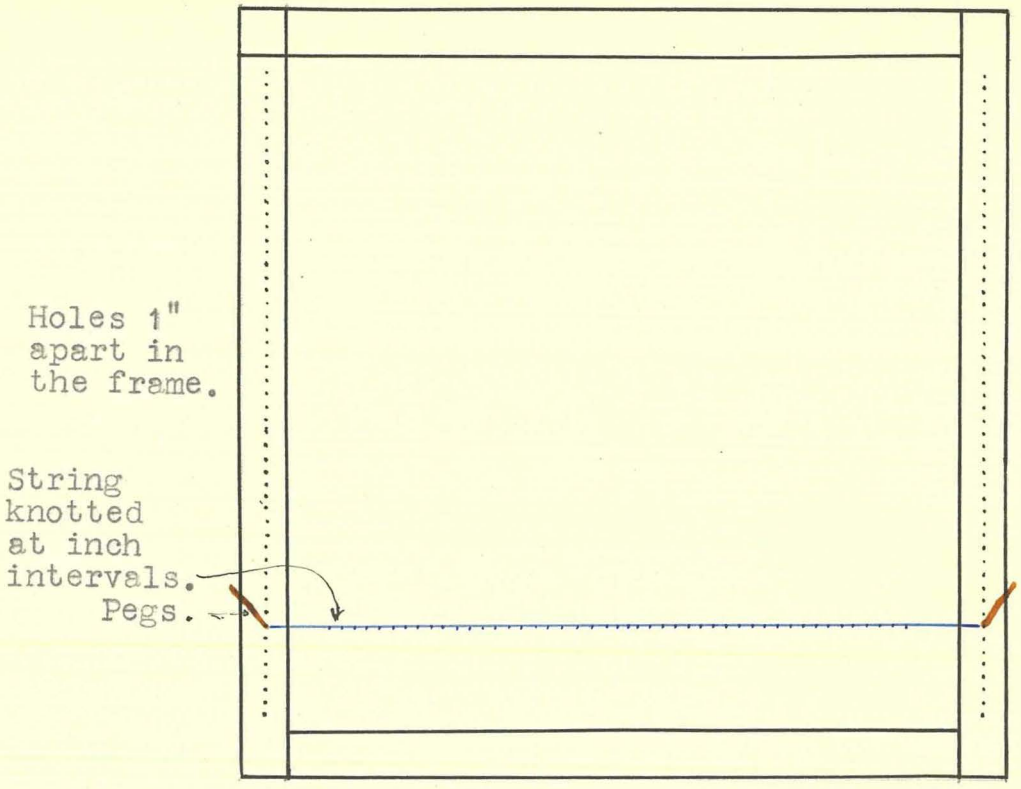


FIG. 3a. Diagram of the frame used for transplanting.

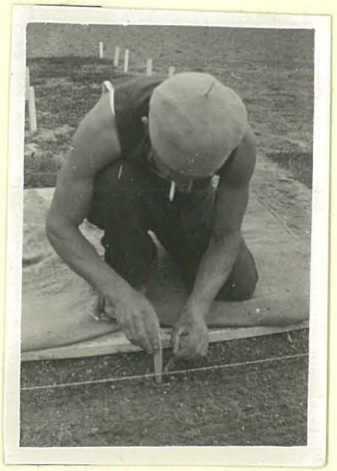


FIG. 3b. The frame in use.

in this instance. In the first place the Ryes were transplanted 4-5 days before the clover and appeared to establish rapidly. On the other hand the clover plants, suffering perhaps to a greater extent from the actual transplanting, also had to contend with considerable competition from the P. Rye. Further, in an effort to reach the light the petioles of the clover became elongated and in consequence cutting almost completely deprived the clover of its leaf surface.

Transplanting extended from Oct. 25th. to Nov. 15th. This is an undesirably long lapse of time between planting plots to be used for compartive purposes due to the possibility of variations in soil and climatic conditions which might differentially influence the establishment and subsequent development of the various plots. Unfortunately the work entailed made it impossible to eliminate this source of error.

The dates of thinning and transplanting were as follows :-

(1) One inch apart series.

Plot Number. (see Fig.2.)	Species.	Date.
1.	P. Rye.	Oct. 25th. 1937.
2.	No.1 Clover	Nov. 4th.
3.	P.P. Clover	Nov. 5th.
4.	P. Rye	Oct. 26th.
5.	No.1 Clover	Nov. 8th.
6.	P.P. Clover	Nov. 9th.
7.	P. Rye.	Oct. 27th.
8.	P. Rye.	Oct. 27th.
9.	P.P..Clover	Nov. 10th.
11.	No.1 Clover	Nov. 11th.
12.	P.P. Clover	Nov. 11th.
14.	No.1 Clover	Nov. 12th.
15.	P. Rye and	Oct. 28th.
15.	P.P. Clover.	Nov. 1st.
16.	P. Rye and and	Oct. 28th.
16.	No.1 Clover	Nov. 2nd.
17.	P. Rye and	Oct. 29th.
	No.1 Clover	Nov. 3rd.
18.	P. Rye and	Oct. 29th.
	P.P. Clover	Nov. 3rd.

(ii) 3" apart series.

Plot Number (see Fig.2.)	Species.	Date.
1.A.	P. Rye.	Oct. 29th. 1957.
2.A.	No.1 Clover	Nov. 15th.
3.A.	P.P. Clover	Nov. 15th.
4.A.	P. Rye	Oct. 29th.
5.A.	No.1 Clover	Nov. 15th.
6.A.	P.P. Clover	Nov. 15th.
7.A.	P.Rye	Oct. 29th.
8.A.	P. Rye	Oct. 30th.
9.A.	P.P. Clover	Nov. 16th.
11.A.	No.1 Clover	Nov. 17th.
12.A.	P.P. Clover	Nov. 17th.
14.A.	No.1 Clover	Nov. 17th.
15.A.	P. Rye and	Oct. 30th.
	P.P. Clover	Nov. 5th.
16.A.	P. Rye and	Oct. 30th.
	No.1 Clover	Nov. 5th.
17.A.	P. Rye and	Oct. 30th.
	No.1 Clover	Nov. 5th.
18.A.	P. Rye and	Oct. 30th.
	P.P. Clover	Nov. 5th.

(c) Routine care of the Plots:

1. Weeding: This involved keeping the plots as free as possible from other species of plants. Many weeds were found coming in, Staggerweed (Stachys arvensis) and Spurrey (Spergula arvensis) being the most frequent. Clover was seen to come into the P. Rye plots, especially in January and about the middle of February some grass appeared in the Clover plots. It appeared likely at this stage that volunteer grass was appearing in the grass plots but could not be readily detected (except in the 3" plots). A careful examination of the plots on February 28th. 1938 revealed that very little volunteer grass had come into them. Poa trivialis, Poa annua, and Italian Rye were the grasses appearing.

2. Watering: From time to time when the plots were in danger of receiving a severe check due to the dry weather (several spells of which occurred between November 1937 and March 1938) they were watered. The advisability or otherwise of this procedure caused the writer some concern. Though it may have been preferable to allow the seasonal influences to have their full effect and so study the root development under natural conditions so doing would probably have brought about a very serious change in this particular season in the 1" apart plots. It was decided that in view of the abnormal season watering the plots was justified. Nevertheless the possible effect on the roots such as induced surface roots, must be remembered.

3. Cutting: This was done every Monday, half the plots being cut each Monday and all on alternate Mondays (See Fig.2.).

The edges of the plots were trimmed at each cutting to ensure the maintenance of the correct dimensions.

The method of cutting was as follows :-

Since the plots were too small to allow of the use of a lawnmower and grass catcher and it was necessary to clip the grass and remove it from the plots for weighing the shears adopted as in Fig. 4 were used and found very satisfactory. They were ordinary type hedge shears with a 1¼" metal rim welded to the upper side of the non-cutting edges of the blades. This adaptation enabled all the leafage to be saved and removed from the plot. The plots from which the leafage was not weighed were cut with a mower.

The cutting aimed at removing the foliage to a level about one inch from the ground. However, it was found that certain other factors had to be considered in cutting.

(i) In the mixed plots (3" apart) it was noticed that after a time the crown of the Rye plants came to be about ½" above the ground level in spite of an attempt to overcome it by tramping. For this reason in order to cut the Clover which was between the rows of Rye to a level comparable with that of the Rye it was found necessary to go along the rows and cut the Rye slightly higher as measured from ground level. This contingency did not arise in the case of the 1" apart plots.

(ii) During a dry spell the ryegrass in the 1" apart plots suffered a severe check and many plants were found to be dying out. At this time cutting was made more lenient.

(ii) When the cutting was commenced on the 1" apart mixed plots it was found that the clovers were unduly affected. This was due to the fact that the clover plants, transplanted between the Rye, failed to develop as rapidly as the P. Rye and, in order to compete with the stronger growing and already established Rye, had to become erect in habit and the petioles became elongated. Consequently when the plots were cut one inch from the ground the clover was almost completely defoliated.

(iv) During the Months May, June and July the growth of clover was negligible and the clover plots were not cut. The ryegrass plots were also cut less frequently.

III. Taking the Samples.

(a) Method:

A sampler, devised by Jacques (6) was used. It consisted essentially of two pieces of angle iron which gave inside dimensions when completed of $2\frac{9}{16}$" x $2\frac{9}{16}$" x 13". On one of these pieces were four lugs with countersunk bolts welded into them and on the other were 4 lugs with holes bored into them. The holes were opposite the bolts so that the two pieces could be bolted firmly together. See Fig. 5.

Welded to the upper lugs carrying the bolts were two extractor chains each 8" long, one of which was fitted with a hook so that the two chains could be joined to form a loop over the sampler. By means of these chains the sampler could be pulled out of the ground. A metal cap of $\frac{1}{8}$" plate with sides

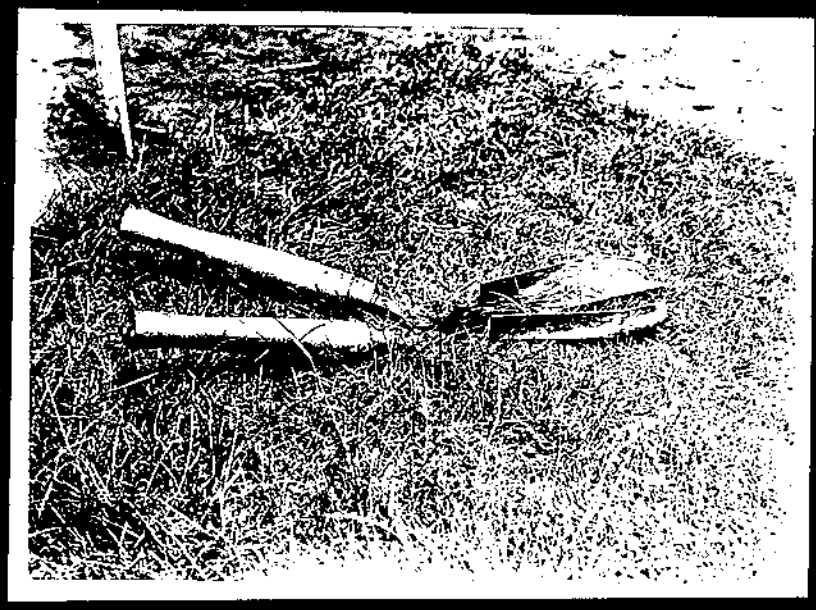


FIG. 4. Hedge clippers (shears) adapted for cutting and collecting herbage.

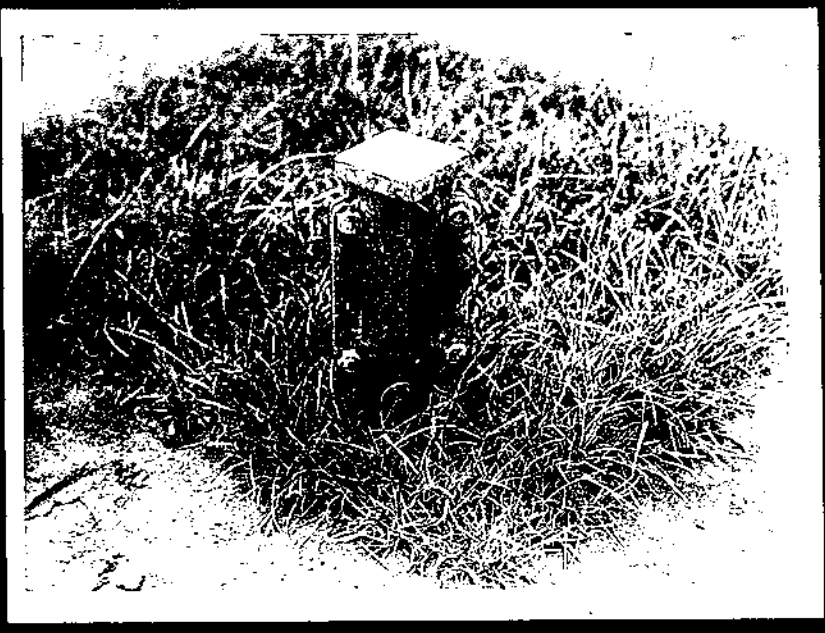


FIG. 5. Sampler in position to take a root sample.

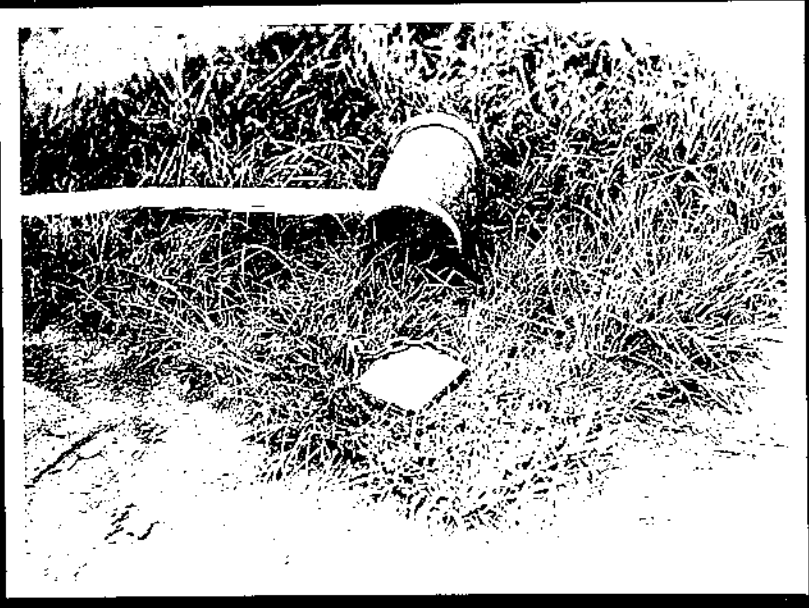


FIG. 6. Sampler driven in. Note maul used and extractor chain.

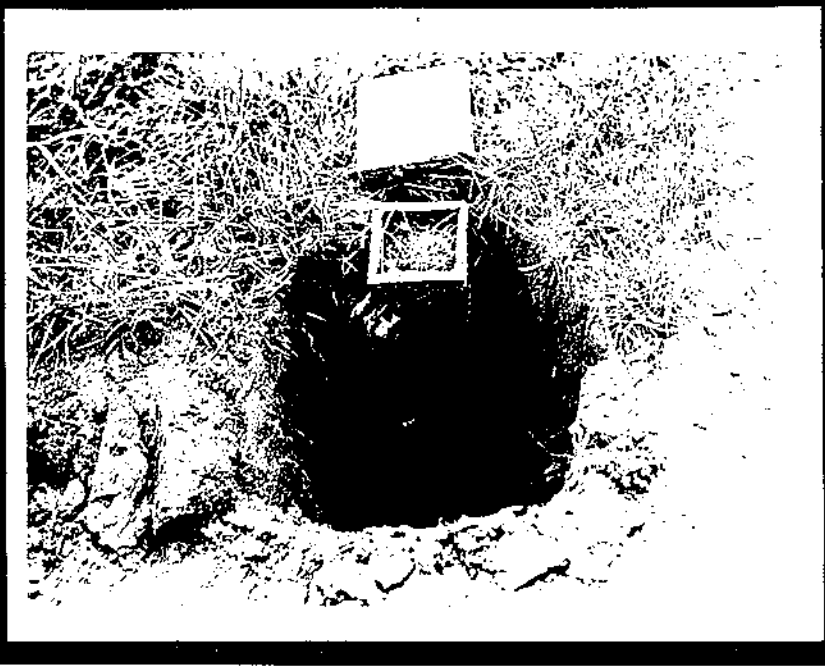


FIG. 7. Sampler being excavated. Note hole dug on the outside to avoid damage to the remainder of the plot.

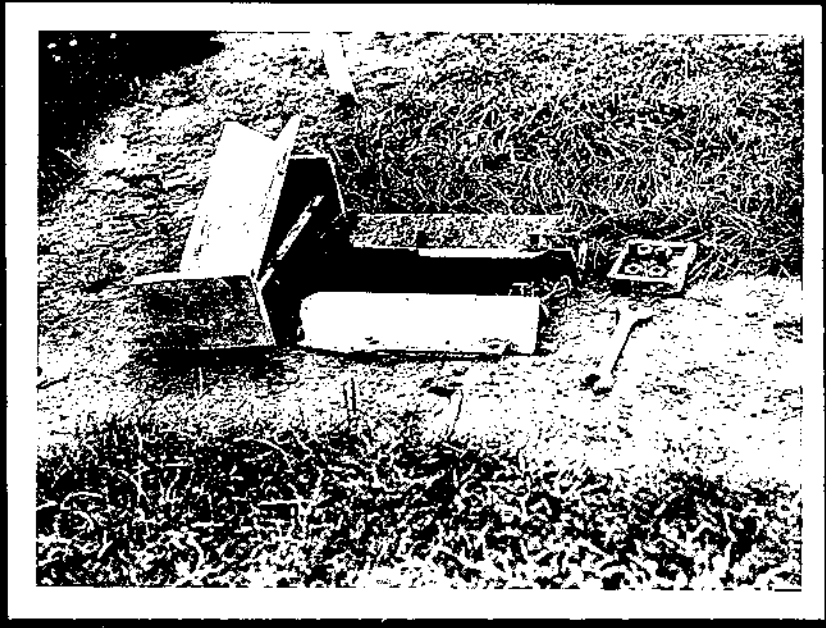


FIG. 8. Sampler unscrewed showing prism of earth etc,.

FIG. 9. Box inverted over the prism of earth in the sampler.

FIG. 10. The whole inverted.

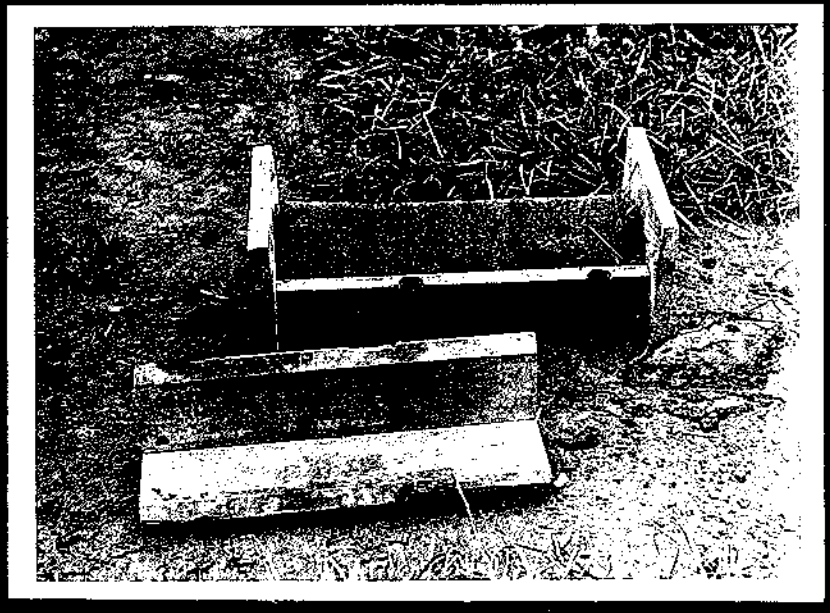


FIG. 11. Sample in box.

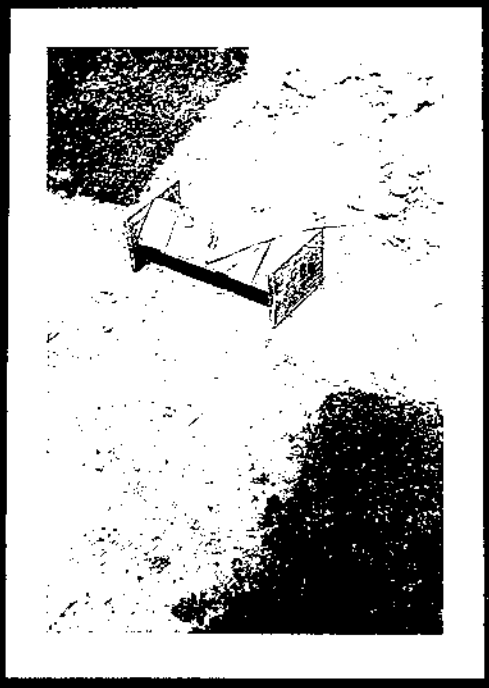


FIG. 12. Sample ready for transport.

welded on to it was placed over the top of the sampler (as shown in Fig. 5) to protect the rim when driving the sampler into the ground.

In taking a sample the two pieces of the sampler were bolted firmly together and the cap placed on top (see Fig.5). It was then placed in position to take the required sample and driven in with a maul until the top of the sampler was level with the surface of the soil (see Fig. 6). The sampler was normally (as described by Jacques (8)) removed by hauling it out by means of the chain or extractor shown in Fig. 6, but this method occasionally gave an incomplete and consequently useless sample due to the fact that, especially in dry weather, the bottom of the sample tended to break away irregularly and sometimes the lower 1 - 1½ inches of the sample were not extracted. As the plots provided only a few more samples than those actually required in the course of the experiment an extra precaution was taken to ensure each sample being complete. The soil on the side of the sampler remote from the unsampled area of the plot was dug away (see Fig. 7). The top of the sampler was tapped inwards i.e. against the remaining wall to make sure that the bottom of the sample broke away cleanly and level with the lower end of the sampler.

After the sampler was removed the nuts were unscrewed and the half (without the bolts) was removed. (See Fig.8) and the sample box inverted over the sample (see Fig.9). The whole was then inverted (see Fig.10) the remaining half of the sampler

removed leaving the prism of soil in the box (see Fig.11). The lid was then put on and securely tied and the sample was ready for transport to the laboratory (Fig. 12).

The hole from which the sample had been removed was filled in and lightly tramped.

(b) Position of Taking the Samples:

This was determined according to the following plan:-

(i) One inch apart Plots: All samples were taken at least 6" from the edge of the plot. The first one was taken in the corner of the plot 6" from each edge and the second 6" from the first, and so on so that the first 4 samples formed a row parallel to the edge. The next 4 samples would be taken in a row parallel to the first and 6" distant (see Fig. 13).

It was intended at the outset to take 6 plants per sample. However, as can be seen from Fig. 15 any number of plants from 4 to 9 can be obtained in one sample. Furthermore, some Rye plants died out and also, especially with the clovers, as the plants grew they tended to lose their original lines so that it became impossible to place the sampler so as to take any given number of plants. The main aim then became to get any number of whole plants, i.e. not cut and mutilated by the sampler.

From the mixed plots it was intended to take one sample of 4 P. Rye and 2 clover plants and one sample of 4 clover and 2 P. Rye plants. However, for the reasons given above and

due to the fact that many of the clover plants died out this was not possible and the sample was taken to include as nearly as possible the average amount of clover that was in evidence compared with the P. Rye.

(ii) 3" apart Series: Sampling was done according to the following scheme : The third plant from each edge was sampled (see Fig.14). Subsequently each third plant was used so that there was always two plants between any two samples or between a sample and the edge of the plot.

In the mixed plots one sample of rye and one of clover was taken at each sampling.

The number of samples to be dealt with allowed of each plot being sampled every 3 - 4 weeks. Weather conditions influenced this routine.

During May and June four samples were taken from certain plots. These four samples were compared to ascertain the variation of the individual samples from a given plot at a given time, and during this time the routine samples were not taken.

Plots Sampled: As will be seen from Fig.2 duplicates of the pure plots were planted and the method adopted was to use one for root sampling and to weigh the production from the other to ascertain the yield of herbage.

While the additional value of results from duplicated (or preferably replicated) plots is fully realised another factor had to be considered. Only a limited number of samples could be

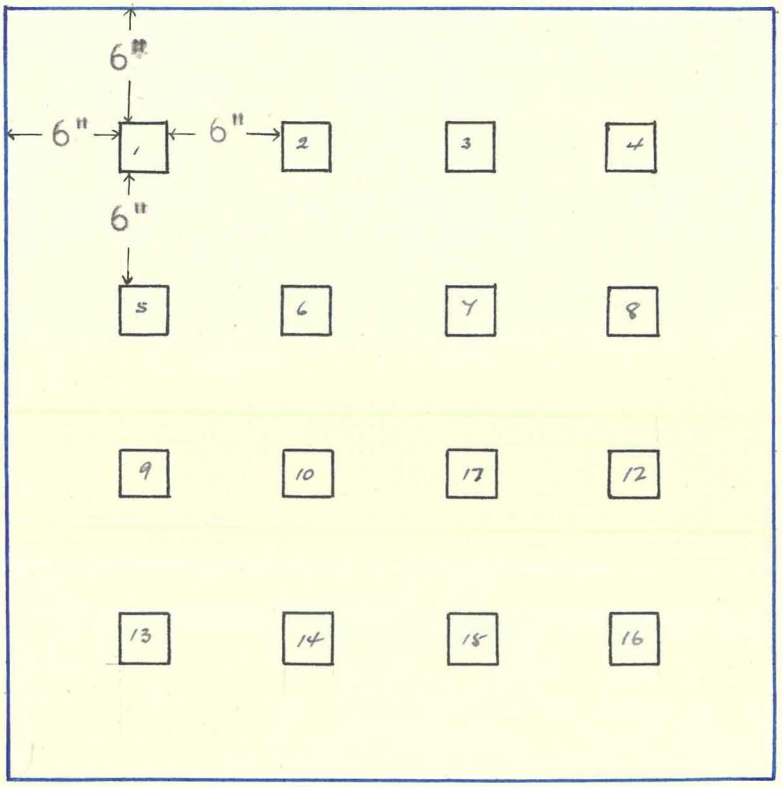


FIG. 13. Positions from which samples are taken in the plots with the plants 1" apart.

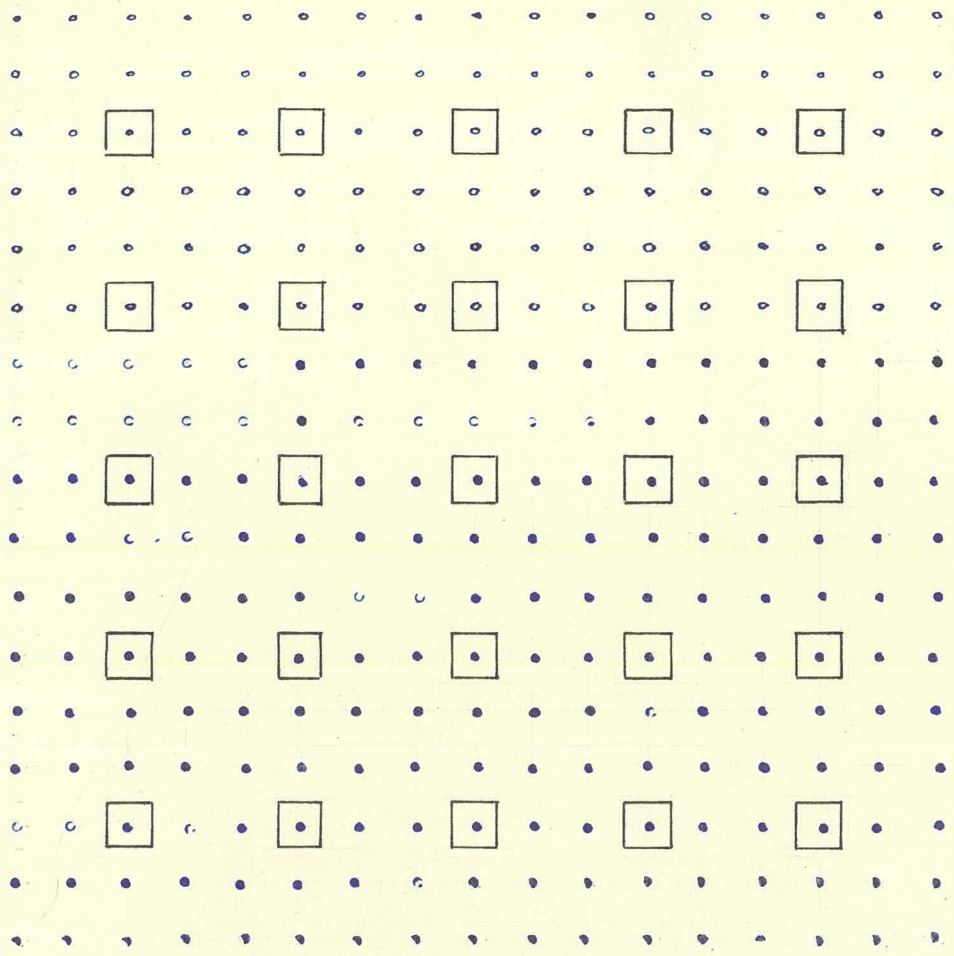


FIG. 14. DIAGRAM SHOWING POSITION OF SAMPLING IN 3" APART SERIES.

DOTS INDICATE PLANTS & SQUARES POSITION OF SAMPLES.

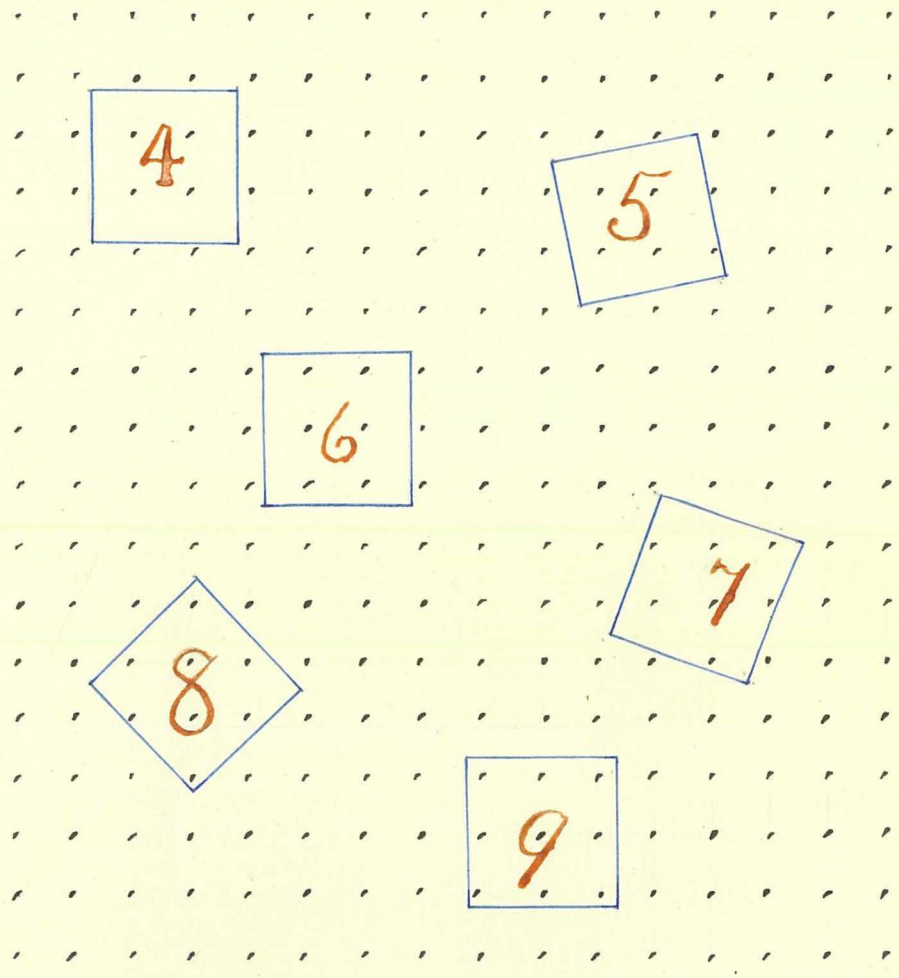


FIG. 15. SHOWING HOW, BY SLIGHTLY ALTERING THE POSITION OF THE SAMPLER 4 – 5 – 6 – 7 or 8 PLANTS PER SAMPLE CAN BE OBTAINED FROM THE 1" APART PLOTS.

N.B. PLANTS DRAWN 1" APART AND SAMPLER (BLUE SQUARE) $2\frac{9}{16}$" x $2\frac{9}{16}$"

dealt with and it was considered that 12 samples from one plot were of more value than 6 from each of two plots, since 6 samples would be quite inadequate to give any indication whatsoever of the variations of the root systems during the year.

IV.. Treatment of the Sample in the Laboratory:

(a) Washing:

The sample in the box was cut into 1" layers to a depth of 12". As the sampler was 13" long this could be done accurately in spite of the bottom of the sample breaking away slightly irregularly as was usually the case. If the sample was too dry it was moistened by covering it with a damp cloth for some time before cutting. It was necessary to have the soil slightly moist to facilitate the cutting of the 1" layers, as if they were too dry they would crumble and be difficult to separate cleanly. The cutting was done with a sharp, pointed table knife.

Each inch layer was washed separately on a fine mesh horse hair sieve (Fig. 17) until the roots were free from soil and in this connection a fine spray froma rose (Fig. 16) was found very useful. The roots were then washed from the sieve into a glazed earthenware bowl from which they were removed with forceps and subjected to the necessary examination in water in a Petrie dish. The few fine roots remaining in the bowl were obtained by pouring the water and roots on to a 'filter'. This 'filter' was in the form of a rubber brush (see Fig.18). The roots that were separated out were cleared from the 'filter' by

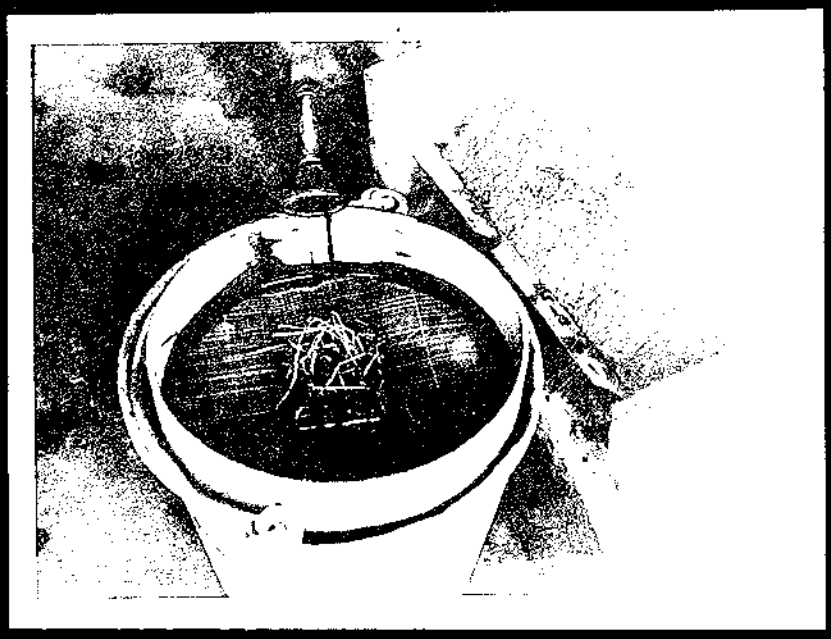


FIG. 16. A view of the laboratory apparatus showing the top inch layer in the sieve and the rose used for washing.

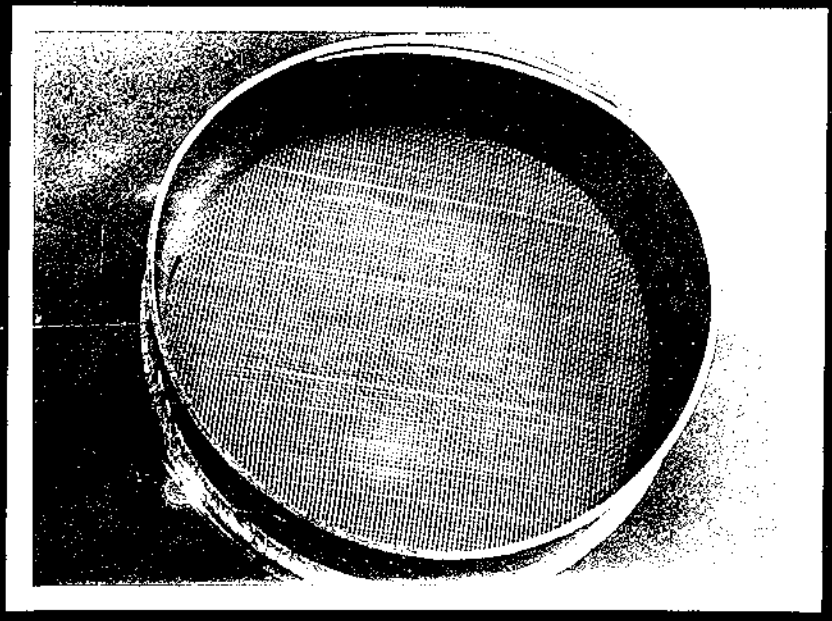


FIG. 17. The sieve.

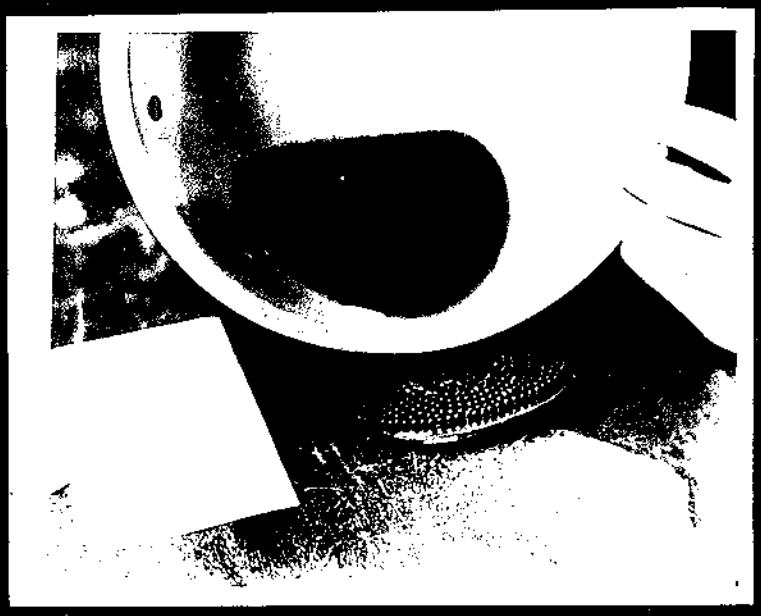


FIG. 12. 'Filtering' out the fine roots.

tapping it sharply on a clean piece of plate glass; they were gathered from the glass with a knife.

Washing was done in a horse hair sieve as described and the sieve approximated to a 16 I.M.M. sieve, i.e. it retained a similar fraction to an 16 I.M.M. sieve though it would not have 16 holes to the linear inch as the I.M.M. would.

It was found later that this sieve was the source of considerable error which would be difficult to eliminate since a finer sieve, while retaining the finer roots, would also retain the fine soil particles and partially decayed organic matter, which material it was found almost impossible to separate from the roots. Therefore, failing anything more convenient this sieve had to be used. The horse hair sieve had one advantage in that the roughness of the horse hair tended to hold the roots while allowing the soil particles to pass through.

After the necessary examination had been carried out the roots were wrapped in blotting paper, adequately labelled, and put into a labelled envelope to be dried and weighed.

(b) Examination:

1. Roots of P. Rye:

(i) The top inch was examined for the following points. First the number of plants was ascertained if this were possible. Sometimes the plants had been mutilated in sampling rendering counting them difficult and inaccurate. Next the roots were cut close up to the tillers with a scalpel and the number of tillers and the number of roots counted and recorded. The main roots

were then stripped of their laterals and the mains and laterals wrapped separately.

(ii) In the subsequent layers the mains and laterals were separated for as many layers as possible. However, at 3 - 4" the mains were so fine that it was impossible to distinguish them macroscopically and later it was decided to separate them only in the top inch.

(iii) General observations such as condition of the tillers and roots, and presence of stones in the soil were recorded.

2. Roots of White Clovers:

(i) The top inch was dealt with first. The tap roots were separated from the runners and the number of tap roots recorded. In the 3" plots there would be only one tap root. The laterals were then separated and wrapped in the same way as the P. Rye roots.

(ii) In subsequent layers the lateral and main roots were not kept separate. In all layers the number of nodules was counted and classified, visually, into four arbitary divisions which approximated to the following sizes :

Division.	Size (Length of Nodule).
1. Very Small	Less than 0.8 .m.m.
2. Small	0.8 to 1.4 m.m.
3. Medium	1.4 to 2.1 m.m.
4. Large	Larger than 2.1.

The classification would naturally vary with different workers, but with practice the method was found to give a rapid indication of the relative sizes of the nodules in the various samples.

(iii) General observations of the condition of the roots and nodules were noted.

3. Roots in Sample from Mixed Plots.

The samples from the mixed 1" apart plots contained rye and clover roots which it was hoped to separate. However, though it was possible to distinguish visually a large percentage of the roots this method was not satisfactory. Several methods were tried such as dyeing the root but proved unsuccessful.

Therefore the roots were separated only in the first inch. The number of rye roots and tillers were counted as were the number of nodules on the clover roots.

In the case of the 3" plots a rye and clover sample was taken at each sampling. As the roots spread the samples came to contain rye and clover roots and the separation could not be regarded as satisfactory.

(c) Weighing the Roots.

It was found that the dried roots varied considerably in weight with varying temperature and humidity, differences of up to 5% being obtained. It was, therefore, desirable to standardise the method of weighing, ~~q.v. page~~ .

The technique adopted was to dry the roots for several days at room temperature and then to transfer to a room where the temperature was maintained at 68°F. and the relative humidity at 60 to 65%.

The temperature was kept at 68° very accurately by a thermostat and the Relative Humidity was controlled by a fan directed on to large shallow dishes of brine solution.

A hygrograph record indicated that violent fluctuations in the outside atmosphere were reflected to a lesser extent in the room due to the inadequacy of the brine solution as a means of controlling humidity. To obviate this error weighing was done when the humidity had remained constant for some time, usually 24 hours, though this was probably considerably longer than actually necessary.

For speed and convenience a Bunge balance was used and taken as weighing correct to 0.3 milligram. Root weights were recorded in milligrams.

V. Method with the Pots.

(a) Purpose:

These were intended to supplement the data from the plots and to provide a means of studying the root system as a whole under the various treatments.

(b) Laying Down:

The pots were 12" diameter glazed drain pipes 12" long sunk vertically into the ground their tops being level

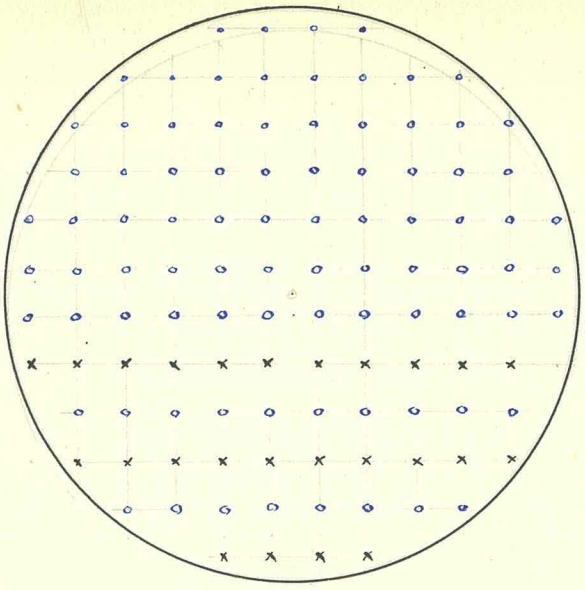


FIG. 20. Method of planting the 1" spaced pots.

N.B. In the mixed pots alternate rows were planted as shown in the lower part of the diagram.

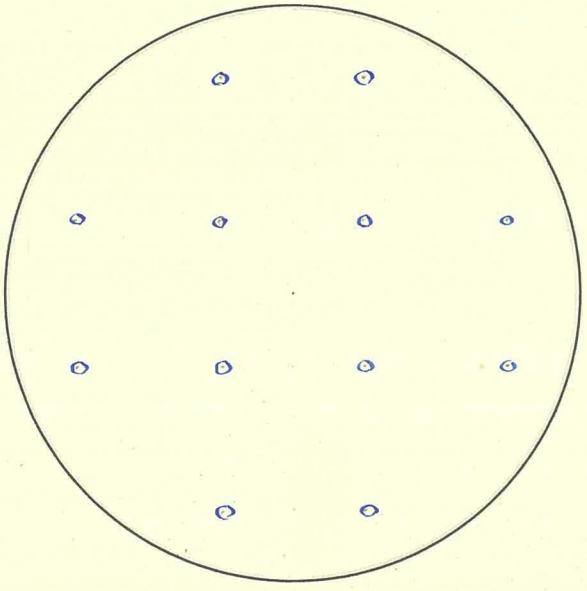


FIG. 21. Method of planting the 3" spaced pots.

N.B. In the mixed pots alternate rows were planted.

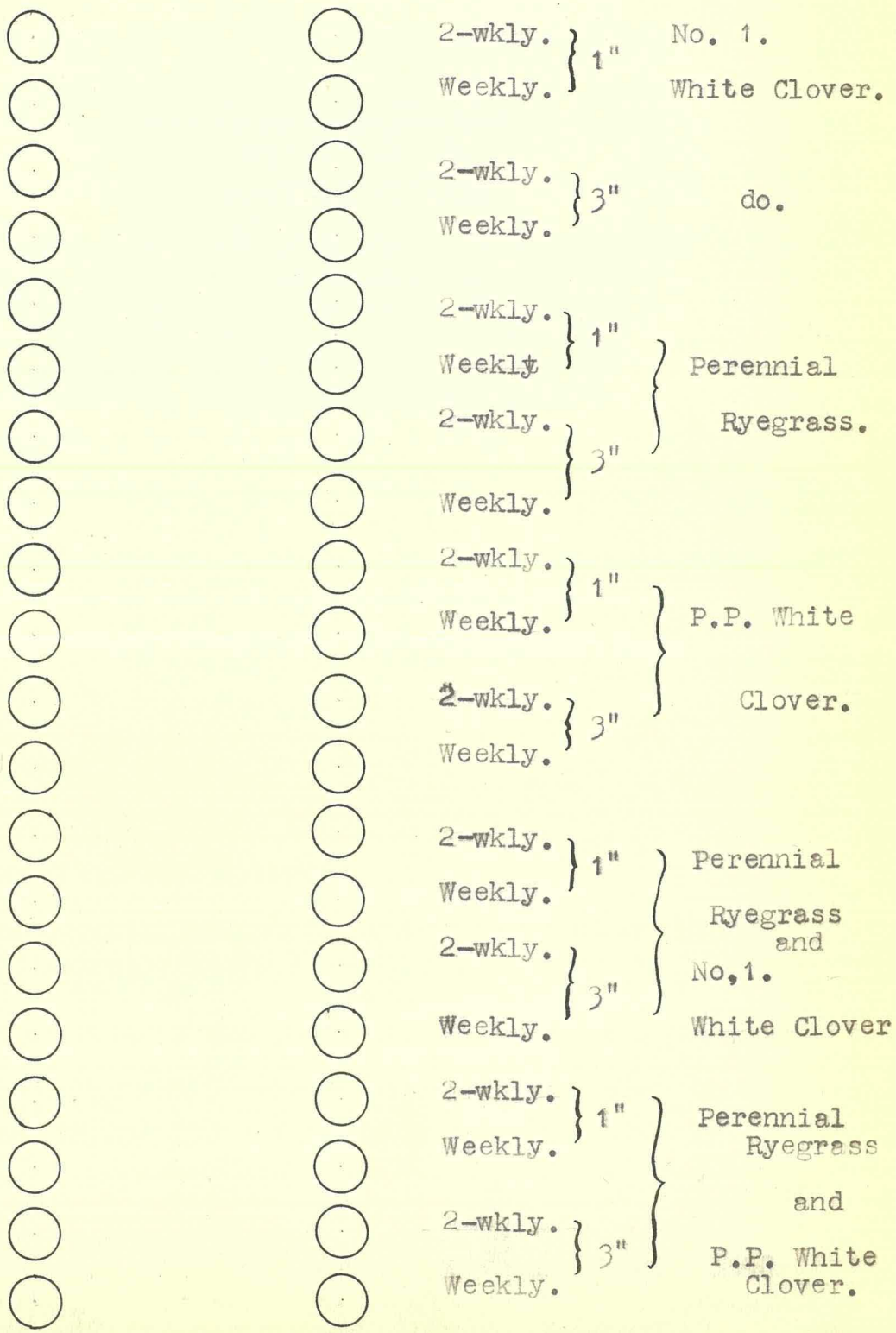


FIG. 19. Diagram of the Pots.

with the surface of the soil. They were filled with a mixture of 6 parts of loam to 1 part of sand. This was found to be a soil with a suitable texture to allow of its being readily washed away from the roots while still providing a suitable medium for root growth.

For a plan of the pots see Figure 19.

Plants from the plots were used and were transplanted on November 22nd. and 23rd. 1937. In the pots in which the plants were to be 1" apart planting was commenced ½" from the edge of the pot and proceeded in 1" rows. See Fig. 20. The string knotted at inch intervals was found convenient for the purpose. In the mixed pots alternate rows of Rye and Clover were planted.

The position of the plants in the 3" apart series is indicated in Fig. 21. The centre 4 plants only were used for examination. In the mixed 3" pots 2 clover and 2 rye were examined.

From the centre of the 1" apart pots 8 plants were chosen at random, while in the mixed pots 4 clover and 4 rye plants were taken.

Routine Care: As for the plots.

(c) Method of Studying the Roots:

The first lot of pots was lifted on March 24th. and 25th. and the second on August 28th., 1938.

Each pot was excavated and the lower end trimmed level with the bottom of the pipe. The plants required for

study were then marked by tying a piece of coloured string round the crown.

Washing was commenced at the lower end of the pot, a fine spray of water with low pressure being used. The soil washed away readily.

The mass of plants from each pot was then taken to the laboratory where it was placed in water and the selected plants separated from the others. This involved a considerable amount of care to avoid loss as the roots were very tangled, especially with the rye, due to the intermingling of the roots in the natural state.

Treatment of the Plants:

(a) Rye: The roots were cut from the tillers and the number of tillers and roots counted and recorded. All the roots of each plant were wrapped in blotting paper and labelled, and, when dry these were weighed as for the samples from the plots.

(b) Clover: The roots were cut from the plant and those of each plant wrapped separately and labelled. The nodules were counted as for the samples from the plots. The roots were later weighed.

VI. Method of Measuring Production of Leaf.

(a) Cutting:

In order to determine the yield of the various plots the production of leaf from an area of each was weighed.

The area taken in the 1" apart was 40" x 20" or half a plot.

In the 3" apart pure plots an area of 51" x 24" was taken and in the mixed 3" plots 54" x 24".

It should be mentioned that all the mixed plots were being sampled and the production from half of each of them was weighed. As the sampling encroached on the area which was being used to give production weights the weighing of the green matter had to be discontinued. There were duplicates of all the pure plots and the production from these duplicates and not the actual plots used for sampling was weighed. See Fig. 2.

The grass was weighed immediately it was cut and the weight recorded. The leafage from the mixed plots was kept and as soon as possible the clover was separated from the P. rye and each weighed separately. Some loss in weight had occurred and the weight of clover and rye was converted to proportions of the original weight. This assumes a similar proportional loss of weight from both clover and P. rye. Taking the green weight only has serious limitations and this aspect is dealt with later. The necessary cutting was done on each Monday and did not commence until after the grass had dried, i.e. after the dew had gone. The choice of Monday proved particularly fortunate since rain occurred on but few occasions. When it did cutting was postponed till the next day.

The production from the pots was similarly weighed and in the case of the mixed pots the clover and P. rye were separated.

Value of Dry Matter Weights.

Relative to this Hudson (12) can be quoted in full:

"Green versus dry matter weights of herbage :

Generally speaking, the determination of yields in terms of dry matter is desirable for the following reasons :- (i) differences in height or density of growth influence the amount of external moisture which it is not always possible to eliminate; (ii) rapid growth induced by a fertilizer treatment frequently results in a lowering of the dry matter content; (iii) I think it is equally safe to state that in most cases rapidly growing species or rapidly growing strains have lower dry matter contents than less rapidly growing ones.

"It is not always possible to make the herbage as dry as is desired for cutting and weighing, and the determination of dry matter eliminates much doubt. Where a comparison is being made between treatments or strains which do not differ markedly a reasonably accurate measure of the relative merits of the respective treatments may be obtained from green weights. Where differences in yield or habit of growth are considerable, that treatment yielding the greatest bulk of green herbage is likely to be unduly favoured by the comparison of green weights, by virtue of the fact that not only is it certain to hold more external moisture, but it will probably have a higher moisture content in itself."

It can be seen from this that the determinations of dry matter contents would have been desirable, but that, since

the growth and habit of the plots to be compared was not markedly different, the green matter weights obtained give a satisfactory indication of the relative yields.

D. RESULTS AND DISCUSSIONS.

I. Effect of Different Rates of Defoliation: Perennial Ryegrass in Pure Plots.

(a) Plants one inch apart in plots.

1. Effect on tiller and root numbers and tiller root ratio..

The more frequent cutting has reduced the number of tillers per sample by 17%. (See Table I and Graph 1).

TABLE I.

Root Numbers and Tiller Numbers in Plots with Plants 1" Apart.

	No. of Samples.	Tiller No.	Root No.	Ratio Tillers to roots.	No. Tillers. (2 weekly = 100)
Cut at weekly intervals.	16	677	3617	1 : 5.3	83.2
Cut at two weekly intervals.	16	814	4263	1 : 5.2	100.0

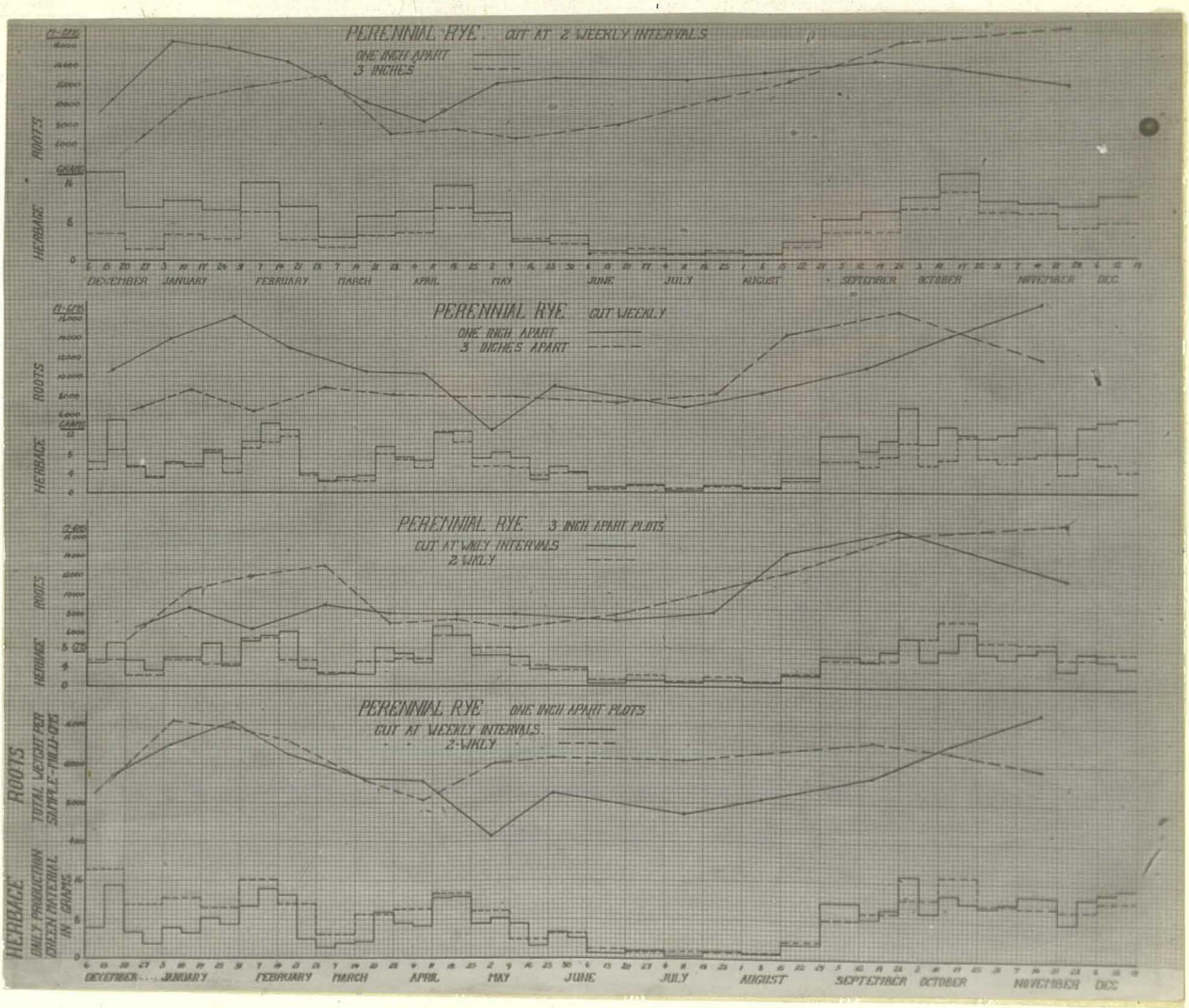
Similarly cutting at weekly intervals has reduced the number of roots but the number of roots per tiller (tiller/root ratio) is slightly less under the two weekly cutting.

The reduction in tiller number is in agreement with Jacques (6) and other workers,but they also found a reduction in tiller root ratio which does not occur here.

2. Effect of defoliation on root weights.

Under the system of more frequent defoliation the weight of roots has been reduced. While the difference is not


GRAPH. 1.
Plants 1" apart in plots.
Cut at weekly intervals.
Cut at 2 weekly "
80
70
60
50
40
30
20
10
ber of Tillers per sample.



GRAPH. 2. The lower section of the graph shows the daily production of herbage (block) and the weight of roots per sample under weekly and 2-weekly cutting in the plot in which the plants were one inch apart.

The section above this shows the same for the plots in which the plants were 3" apart.

In each case the broken line indicates the production from the plot cut at 2 weekly intervals.

Errata : Weight of roots should read 800 (1200) mgms not 8000 (12000) etc as shown.

GRAPH. 3.

Plants 1" apart in plots.

Reference.

Cut weekly

Cut at 2 weekly intervals

Weight of lateral roots. (0-1")

M-gms.

400

300

200

100

Weight of main roots (0-1")

M-gms.

300

200

100

0

Nov. Dec. Jan. Feb. Mar. Apr. May. June July Aug. Sept. Oct. Nov.

GRAPH. 3.

significant it can be taken as indicative of the trend of root behaviour.

From the bottom section of Graph 2 it will be seen that within the limits of the sampling error the weights of the roots obtained from the weekly and two-weekly cut plots were very similar from December to April and it was only after this till October, i.e. during the dormant season and the commencement of spring growth, that the marked superiority of the plot cut at two-weekly intervals became apparent.

The increase in weight over this period can be attributed in a large measure to the increased weight of the main roots. This may indicate an increased food storage, though this is doubtful. This increase is shown in Graph 3.

The weight of laterals does not show this consistent increase under the more lenient cutting.

3. Corroborative evidence from the pots.

(i) Tiller and Root numbers:

Evidence from plants grown in 12" glazed drain pipes (i.e. the pots) and otherwise given similar treatment does not confirm the results obtained in the plots. From Table II it can be seen that the number of tillers per plant is very similar under both treatments, while the tiller/root ratio is less under the more lenient cutting. As shown in Table III, however, the root weights indicate a more vigorous development under the two-weekly cutting.

TABLE II.

Per. Ryegrass Plants 1" Apart in Pots.

Tiller No., Root No., and Tiller -.root Ratio.

	No.of Plants	Pots lifted March Tillers	Roots	Ratio	No. of Plants	Pots Lifted August Tillers	Roots	Ratio
at weekly intervals.	8	129	557	1:4:3	8	90	432	1:4.8
at two-weekly intervals.	8	126	516	1:4.1	8	88	354	1:4.0

(ii) Root Weights:

As was the case in the plots the root weight has been reduced by frequent cutting. The results are shown in Table III.

TABLE III.

Root Weights of P. Rye. Plants 1" Apart in Pots.

	No. Plants.	Pots Lifted March.	Pots Lifted August.
Cut at weekly intervals	8	355.0 mgms.	390.0 mgms
Cut at 2-weekly "	8	575.0 "	413.0 "

(b) Plants three inches apart in plots.

1. Tiller and root numbers and tiller/root ratio.

With the wider spacing of the plants in the plots a lesser tiller number by 17.5% was found on the less frequently

defoliated plot. Both Table IV showing the total number of tillers from 16 samples from the plots cut at weekly and the plot cut at two-weekly intervals and Graph 4 showing the seasonal trend of tiller numbers from the two plots, amply demonstrate this point. A fairly consistent increase throughout the season is shown in Graph 4.

Since one plant was taken per sample the number of tillers per sample is the same as number of tillers per plant.

TABLE IV.

Pure Ryegrass Plots with Plants 3" Apart.

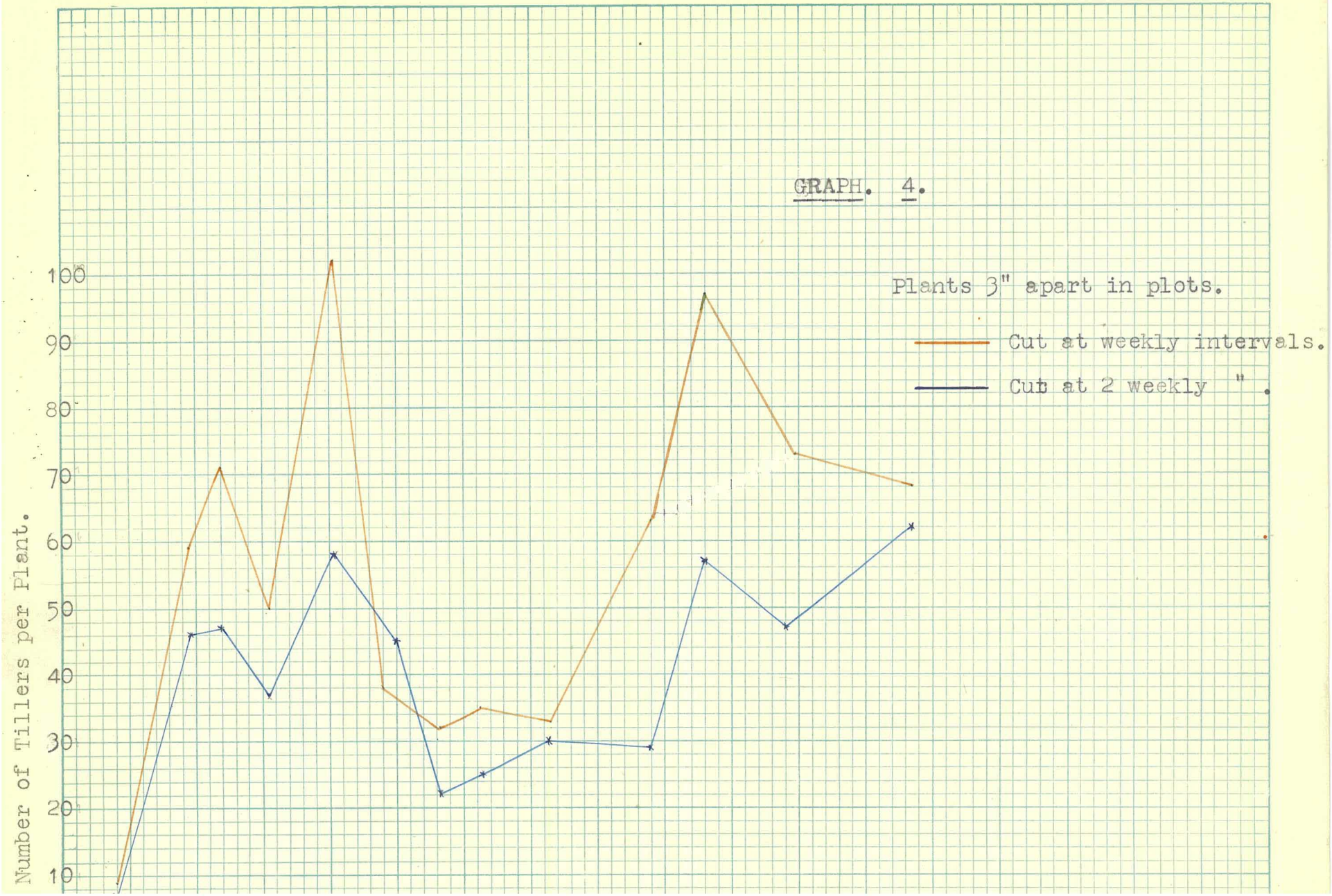
Showing Tiller No. Root No. and Ratio Tillers : Roots.

	No. of Samples	Tillers	Roots	Ratio of Tillers to Roots	No. Tillers. (Weekly = 100)
at weekly intervals	16	829	3537	1 : 4.3	100.0
" 2-weekly "	16	601	3122	1 : 5.2	72.5

These results are not in agreement with Jacques (6) who found frequent defoliation reduced tiller numbers of uncertified P. Rye. Roberts and Hunter (9) using an English Perennial Ryegrass found a reduction in tiller number under more frequent cutting.

In this case the weekly cutting has materially reduced the number of roots per tiller which is in agreement with the above workers.

GRAPH. 4.


Plants 3" apart in plots.
Cut at weekly intervals.
Cut at 2 weekly " .
Number of Tillers per Plant.
100
90
80
70
60
50
40
30
20
10

2. Root Weights.

With the exception of the first four months of the experiment (November, December, January, February) the weights of roots from the weekly and two-weekly cut plots were very similar. The period December to February shows a root weight in favour of the less frequent cutting. (See Graph 2 opposite page). The total root weight from 16 samples from the plot cut at two-weekly intervals is greater than that from the weekly cut plot (See Table V). The difference, however, is not statistically significant.

TABLE V.

Root Weights from Pure Ryegrass Plots with plants 3" Apart.

	No. of Samples.	Weight in Milligrams.
Cut at weekly intervals	16	~~11046.5~~ 10465.4
Cut at two-weekly intervals	16	12068.3

3. Corroborative Evidence from the Pots.

(i) Tiller and root number and tiller-root ratio.

As mentioned, two series of pots were given similar treatment, the only difference being that one series were allowed to grow to a later stage than the other, one series being lifted in March and one in August. The results from the two series of pots containing pure P. Rye. spaced 3" apart are

conflicting and it is evident that the more frequent cutting had no marked effect (see Table VI.)

It can be seen that the tiller - root ratio is less under the frequent cutting and this is in agreement with results from the plots.

TABLE VI.

Pure P. Rye. Pots with Plants 3" Apart.

Tiller No., Root No., and Tiller-Root Ratio from 2 Sets Pots.

	No. of Plants.	Pots lifted March Tillers	Roots	Ratio	Pots lifted Aug. Tillers	Roots	Ratio
t Weekly intervals	4	152	469	1:3.1	121	352	2.9
t two-weekly intervals	4	142	618	1:4.1	128	612	4.8

4·8

(ii) Root Weights:

Both series of pots of pure P. rye. 3" apart show a decrease of root weight under the more frequent cutting system as compared with the two-weekly (see Table VII) and is in agreement with the findings in the plots.

TABLE VII.

Root Weights (in milligrams) of P. Rye in Pots with Plants 3" Apart.

	No. of Plants.	Pots lifted March.	Pots lifted August.
Cut at weekly intervals	4	3830.0	1468.0
Cut at 2-weekly intervals	4	4674.0	1580.0

Effect of Different Rates of Defoliation on White Clover:

(a) Plants One Inch Apart in the Plots.

1. No. 1 White Clover.

The frequency of cutting the clover plots appears to have had little effect on the root weights obtained. From Graph 5a (in appendix) it can be seen that the weight of roots from the weekly cut plots and that cut at two-weekly intervals are very similar. The total root weights from 12 samples show a slightly heavier weight under the more frequent defoliation (see Table VIII). The difference is not statistically significant.

TABLE VIII.

Weight Roots No.1 White Clover Plants 1" Apart in Plots.

	No. of Samples.	Weight of Roots.
Cut at weekly intervals	12	7600.4 mgms.
Cut at two-weekly intervals	12	7231.7 "

2. P.P. Clover.

Frequent cutting in this case again has increased root weight. A slight increase throughout is seen in Graph 5b, appendix while the total of 12 samples shows the slightly greater weight from the plots cut weekly (see Table IX.)

TABLE IX.

Root Weights from 1" P.P. Clover Plots.

	No. of Samples.	Root Weight.
Cut at weekly intervals	12	6758.2 mgms.
Cut at two-weekly intervals	12	6287.5 "

(b) Three Inch Apart Plots:

1. No. 1 Clover.

There is very little difference in root weight as a result of more frequent cutting. The slight (1.5%) difference shows the weekly cut plot to have a heavier root weight. (See Table X and Graph 5c. in Appendix)

TABLE X.

Root Weights from No.1 White Clover Plots Plants 3" Apart.

	No. of Samples.	Root Weight.	Root Weight (Weekly = 100)
Cut at weekly intervals	12	6491.6 mgms.	100.0
Cut at 2-weekly intervals	12	6395.2 "	98.5

2. P.P. Clover.

The more frequent cutting in this case has increased root weight. A consistent increase throughout the season can be seen from Graph 5d. The figures were subjected to statistical analysis and were found to be bordering on significance. This is shown in ~~Table XI.~~ Appendix D.

N.B. Pages 38 and 39 have been omitted.

3. Corroborative evidence from the pots:

Results from the pots do not agree with those from the plots and in all cases show a decrease in root weight under the more frequent system of defoliation. The results are given in Table XII.

TABLE XII.

Showing Weight (in m-gms) of Roots of Clover Plants from the Pots.

Species.	Frequency of Cutting.	Plants 1" apart. No. of Plants	Pots lifted March	Aug.	Plants 3" apart. No. of Plants	Pots lifted March	Aug.
No. 1 Clover	Weekly	8	355.0	390.0	4	1503.0	1679.0
	2-Weekly	8	575.0	431.3	4	1686.5	1090.5
P.P. Clover	Weekly	8	585.0	461.0	4	1719.5	1033.0
	2-Weekly	8	737.0	651.0	4	2193.0	1669.7

--

Effect of Different Rates of Defoliation:

On the Mixed Plots.

(a) Plants 1" Apart in Plots.

1. Mixed P. Ryegrass and No.1 White Clover.

(i) The effect on tiller and root numbers of the P. Rye. in the plot.

In this instance the more frequently defoliated plot shows the greater number of tillers per sample but has a smaller tiller-root ratio than the plot cut at two-weekly intervals. The position is shown in Table XIII.

TABLE XIII.

P. Rye. and No.1 White Clover Plots with Plants 1" Apart.

Tiller and Root Numbers and Tiller-Root Ratio.

	No. of Samples.	Tillers	Roots	Ratio of Tillers-Roots.	No. Tillers (Wkly.=100)
Cut at weekly intervals.	12	601	2086	1 : 3.5	100.0
Cut at 2-weekly intervals.	12	501	2025	1 : 4.1	83.4

(ii) Effect on Root weight of the No.1 White Clover and P. Rye.

It was found impossible to satisfactorily separate the grass from the clover roots so that for the purpose of this

Table they are necessarily grouped together.

The total root weight was greater under the lenient cutting system. See Table XIV.

TABLE XIV.

Root Weights.

Mixed Plot Containing P. Rye. and No. 1 White Clover.

Plants 1" Apart.

	No. of Samples.	Weight of Roots	Weight of Roots 2-Weekly = 100
Cut at weekly intervals	12	12349.1	79.8
Cut at 2-weekly intervals	12	15464.9	100.0

2. Mixed Perennial Ryegrass and P.P. Clover.

(i) The effect of defoliation on tillers and roots of the Perennial Ryegrass.

A slight decrease of tiller numbers under the more severe system of cutting is observed. The fewer tillers have, however, developed more roots per tiller. See Table XV.

TABLE XV.

No. Tillers No. Roots and Tiller-Root Ratio in the P. Ryegrass

In P. Rye and P.P. Clover Plots with Plants 1" Apart.

	No. of Samples.	Tillers	Roots	Ratio	Tillers to Roots.
Cut at weekly intervals	12	434	2021	1 :	4.6
Cut at 2-weekly intervals	12	452	1914	1:	4.2

(ii) The effect on root weight P.P. Clover and P. Rye.

The total weights of roots from the plot cut at weekly and the plot cut at two-weekly intervals are very similar a very slight advantage of 5% being with the weekly cut plot. See Table XVI.

TABLE XVI.

Root Weights.

Mixed Plot Containing P. Rye. and P.P. White Clover.

Plants 1" Apart.

	No. of Samples.	Weight of Roots	Weight of Roots Weekly = 100.
Cut at weekly intervals	12	13568.3	100.0 99.5
Cut at 2-weekly intervals	12	13492.9	99.5

3. Corroborative evidence from the pots.

The results from the pots again do not agree with those observed in the plots as regards tiller number and Root/Tiller ratio. In the pot containing ryegrass and No.1 Clover a marked reduction of tiller number is noted under the more severe system of cutting while in the pot containing ryegrass and P.P. Clover there appears to be no difference. Table XVII a.

As regards root weights, it will be seen from Table XVII b. that the total weight of roots is smaller in the weekly cut pot but in each case there is little difference in the weight of clover roots, the difference in the ryegrass roots contributing in the main to the total difference.

TABLE XVII a.

Showing Tiller No. Root No. & Tiller-Root Ratio from the Mixed Pots. Plants 1" Apart.

Species in Pot.	Frequency Cutting.	Pots Lifted March. No. of Plants.	Tillers	Roots	Ratio Tiller to Roots.	Pots Lifted Aug. No. of Plants	Tillers	Roots	Ratio Tiller to Roots
Ryegrass and No.1 Clover.	Weekly	8	38	277	7.3	8	53	194	3.6
	2-Weekly	8	63	142	2.3	8	63	176	2.8
Ryegrass and P.P. Clover	Weekly	8	67	267	4.0	8	77	192	2.5
	2-Weekly	8	65	370	5.7	8	73	219	3.0

TABLE XVII b.

Showing Weight Roots from the Mixed Pots. Plants 1" Apart.

Species.	Frequency Cutting.	No. of Plants of each	Pots Lifted March Clover	Ryegr.	Total	Pots Lifted Aug. Clover	Ryegr.	Total.
			milligrams					
Ryegrass and No. 1 Clover	Weekly	4	180.0	705.0	885.0	256.2	360.0	616.2
	2-Weekly	4	256.0	830.0	1086.0	221.0	632.5	853.5
Ryegrass and P.P. Clover.	Weekly	4	147.5	432.0	579.5	154.8	403.0	557.8
	2-Weekly	4	145.0	829.0	974.0	160.0	381.0	541.0

(b) Plants Three Inches Apart in Plots.

1. Mixed P. Rye and No. 1 White Clover.

(i) The effect of defoliation on tiller number, root number and tiller-root ratio of the P. Rye.

The effect of the frequent cutting on these plots has been to reduce the tiller number and also the ratio of roots to tillers. See Table XVIII.

TABLE XVIII.

Tiller No., Root No., Tiller-Root Ratio.

In Mixed Plots Containing P. Rye and No. 1 White Clover.

Plants 3" Apart.

	No. of Samples.	No. of Tillers.	No. of Roots.	Ratio of Tillers to Roots.	Tiller No. 2-Wkly.=100
Cut at weekly intervals	12	688	2700	1 : 3.9	93.0
Cut at 2-weekly "	12	728	3213	1 : 4.4	100.

(ii) The effect of defoliation on root weights of the P. Rye and the No. 1 White Clover.

In the mixed plots in which the plants were 3" apart at each sampling one sample was taken over a P. Rye plant and one over a clover plant. During the first few months each sample appeared to contain only P. Rye or only Clover roots, but as the clover spread by virtue of its runners and the P. rye roots extended laterally the samples were found to contain both clover and rye roots and they could not be satisfactorily separated.

Therefore the figures for root weights obtained are of doubtful value, but it is interesting to note that they show a greater root weight for both clover and rye and a greater total root weight under the more lenient cutting. See Table XIX.

TABLE XIX.

Mixed Plots Containing P. Rye and No.1 White Clover.

Plants 3" Apart.

Root Weight.

	No. of Samples	Weight of Roots. Cut at Weekly Intervals	Cut at 2-weekly Intervals
P. Rye	12	10086.5	11250.3
No.1 White Clover	12	7851.5	9504.1
Total		17938.0	20760.0

2. Mixed P. Rye and P.P. White Clover Plot.

(i) Effect of defoliation on root number, tiller number and tiller-root ratio.

The tiller number is slightly less under the more lenient cutting, while the tiller-root ratio is similar in both plots. See Table XX.

TABLE XX.

Tiller No., Root No., and Tiller-Root Ratio.

In Mixed Plots Containing P. Rye and P.P. Clover.

Plants 3" Apart.

	No. of Samples.	No. of Tillers.	No. of Roots.	Ratio of Tillers to Roots.
Cut at weekly intervals.	12	765	2842	1 : 3.7
Cut at 2-weekly intervals	12	710	2616	1 : 3.7

(ii) Effect of defoliation on root weights of the P.P. Clover and P. Rye.

As mentioned for No. 1 Clover and P. Rye, page 45 the root weights are of doubtful.value, but it is interesting to note that there is a consistently greater weight of both P. rye and clover roots under the more lenient system of cutting. See Table XXI.

TABLE XXI.

Mixed Plots Containing P. Rye and No. P. White Clover.

Plants 3" Apart.

Root Weight.

	No. of Samples.	Weight of Roots (m-gms.) Cut at Weekly Intervals	Cut at 2-Weekly Intervals
P. Rye	12	9443.8	11457.3
No. P. Clover	12	7747.0	8935.7
Total	24	17190.8	20393.0

3. Corroborative evidence from the pots.

The March and August samples from the pots do not agree in many cases and frequently are in conflict with the results from the plots. The two results from the mixed P. rye and No1 White Clover pots agree regarding tiller number and tiller-root ratio but are in the opposite direction to the trend in the plots. The March and August results from the mixed P. Rye and P.P. White Clover pots regarding tiller number disagree. See Table XXII.

The March and August samples agree concerning root weight in the P. Rye and P.P. White Clover plot and agree with the results from the plots.

The March and August samples from the P. Rye and No.1 White Clover pots do not show agreement. See Table XXIII.

TABLE XXII.

Tiller No., Root No., and Tiller-Root Ratio from the Mixed Pots.

Plants 3" Apart.

a) P. Rye and No.1 White Clover.

	Pots Lifted March				Pots Lifted August.		
	No. of Plants	No. of Tillers	No. of Roots.	Tiller-Root Ratio.	No. of Tillers.	No. of Roots.	Ratio of Tillers to Roots.
Cut at weekly intervals	2	49	326	1:6.7	63	266	1:4.2
" " 2-weekly "	2	19	126	1:6.6	33	106	1:3.2

b) P. Rye and P.P. Clover.

Cut at weekly intervals	2	49	251	1:5.1	48	244	1:5.1
Cut at 2-weekly "	2	56	257	1:4.6	30	145	1:4.8

TABLE XXIII.

Root Weight in Mixed Pots - Plants 3" Apart.

	Cut.	No. of Plants of each	Pots Lifted March			Pots Lifted Aug.		
			Clover	Rye	Total	Clover	P. Rye	Total
P. Rye and No.1 White Clover	Weekly	2	1250.0	502.0	1752.0	528.3	969.8	1598.1
	2-Weekly	2	1296.5	1983.0	3279.5	244.0	861.8	1105.8
P. Rye and P.P. White Clover	Weekly	2	540.0	775.0	1315.0	314.5	619.8	934.3
	2-Weekly	2	787.0	1204.0	1991.0	405.5	942.0	1347.5

Discussion of the Effect of Different Rates of Defoliation.

Tiller Number.

Tiller number is so closely related to root development that some consideration is justified here.

As can be seen from the results obtained the effect of cutting is very variable, there being some instances where tiller number is apparently increased while other cases exist where a definite decrease is observed. Discrepancies occur between the results from the plots and those from the corresponding pots. Such discrepancies are to be expected but become the more confounding in this experiment due to the lack of adequate replication and for this reason no definite conclusions can be drawn.

In some plots and pots the more frequent cutting has reduced tiller number which would be expected from a consideration of the results of other workers. Jacques (6) using an uncertified P. rye found a reduction of tiller number under frequent cutting while Roberts and Hunt (9) using an English ryegrass confirm Jacques' results with the uncertified strain.

However, in this experiment in some instances more tillers have developed under the more severe cutting and in the main it has been found that under the 3" spacing tillering has been increased by cutting while under the 1" apart it has been decreased. In the pure P. Rye plots and the mixed P.P. White Clover and P. Rye plots with the plants 3" apart and in the No.1 White Clover and P. Rye plots with the plants 1" apart the more

frequently cut plot has the greater number of tillers. Taking the weekly cut plot as 100.0 in each case the numbers of tillers in the plots cut at 2-weekly intervals are 72.5, 93.3 and 83.4 respectively. Thus half the plots show this reduction.

Three of the twelve pots show it to a marked extent, while five show a slight difference in the same direction.

Since this state of affairs does not agree with the above workers it calls for some comment.

Though there are several factors influencing the issue it is likely that with the vigorous certified strain of P. rye used frequent cutting may tend to increase tillering, a condition analagous with that occurring in certain cereals.

A factor, the importance of which cannot be definitely stated but which may have affected the results, is the effect of the use of the lawn mower. The frequent cutting of the 3" P. Rye plots tended to produce a prostrate habit, i.e. some of the tillers tended to be on the ground. Consequently the mower set 1" above the ground level did not completely defoliate the plants and this residual leaf surface would be of particular importance to the more frequently cut plants. This did not occur in the plots with 1" spacing where competition forced the plants into an erect habit and occurred to a lesser extent in the mixed plots with 3" spacing where the clover would provide some competition. The shears were used to cut the plants in the pots and any tillers lying on the ground would be cut. Thus the plants in these plots and the pots were deprived of a means of maintaining vitality available to the 3" pure P. Rye plots.

While mowing may have encouraged tiller development in some plots competition would be a much more important factor. It is feasible to suppose that the frequent cutting provides a stimulus to increase tillers, and where conditions are favourable the increased number of tillers can maintain themselves. Unfavourable conditions such as competition together with frequent cutting render the tillers so weak that further increase is impossible. Thus in the 1" spaced plots and the mixed plots with 3" spacing (where there is competition from the clover) it would be feasible to suppose that cutting would reduce the tiller number while in the 3" pure plots where competition is less severe a greater tiller number under the more frequent cutting would develop

A potential source of error in interpreting results from the pots has been briefly mentioned, and is worthy of elaboration. In the 1" spaced pots the tiller number and root weight per plant have been quoted, whereas with the corresponding plots the tiller number or root weight per sample, i.e. per unit area (or volume), has been given.

This difference becomes important where, due to competition and the effect of cutting, more plants have died out under the more severe cutting. The remaining plants will not be subject to the same competition as the plants in the less severely cut plot, assuming these are all able to survive. In this case the fewer plants under the more severe cutting might be expected to thrive better than the greater number under the less severe cutting and would then have a heavier root weight and a greater

tiller number per plant. This is likely to be misleading in interpreting results from two pots subjected to different rates of defoliation.

Again, though the weekly cut plot had a greater tiller number and root weight per plant it would not necessarily be greater per unit area or unit volume and consequently the results are not strictly comparable with the plots where tiller number and root weight per unit area or volume are being considered.

Root/Tiller Ratio.

From a consideration of the results it would appear that the ratio of the number of roots to the number of tillers is not determined simply by the frequency of cutting. Various workers using single plants and/or pots have indicated that the tiller/root ratio is directly proportional to the frequency of cutting but under the more natural growing conditions in the plots it would seem that other factors must be considered. In the main it appears that where the twoweekly cut plots have a greater tiller number than the corresponding plots cut weekly they have a smaller tiller/root ratio.

Jacques (6) has mentioned that the new roots are produced on the new tillers and further that there are two meristems in the plant competing for the plant's nutrients. Thus two factors appear to be involved - number of tillers and supply of nutrients -. Due to the continual depletion and the smaller leaf surface available for photosynthesis the weekly cut plants have a smaller supply of nutrients to provide for growth than has

the plots cut at two-weekly intervals. Where then there are fewer tillers in the weekly cut plot the plant is able to support them as well as the plot cut at two-weekly periods can support a greater number, i.e. the factors cancel out.

Where, however, the weekly cut plant has the greater number of tillers it definitely cannot continue to support them and the tiller/root ratio is decreased. Conversely few tillers under the two-weekly cutting can be relatively well supplied with nutrients giving tillers which can produce many roots and therefore a high tiller/root ratio. Thus the roots are produced according to the ability of the plant to supply nutrients to the root meristem and this is provided not simply by the frequency of cutting but by competition for nutrients from the shoot meristems which in turn is determined by the number of tillers developed and how frequently they are cut.

Root Weights.

P. Rye. Consistent with the results of other workers it has been found that root weight has been decreased by frequent cutting. As mentioned, the differences are not statistically significant but the trends are definite. While the differences are not great it is of importance to note that for the most part the difference is due to the greater weight of main roots in 0" to 1" layer. This may indicate an increased storage of reserves in the two-weekly cut plot, but this is doubtful.

In the clover plots the root weights show consistently higher figures under the more frequent cutting approaching statistical significance in one instance, while in the pots frequent cutting has reduced the root weight in all cases. Though the results from the plots may be fortuitous their consistency demands comment. Observations of the plots indicated that the frequent defoliation was inducing a creeping habit, many long runners being observed in the weekly cut plots which were not present in the two-weekly, and the weekly cut plots tend to show better covering than the two-weekly. This may, in part, explain the heavier root weight in the plots. In the pots the runners were mainly cut and would not allow of the extent of creeping that would occur in the larger plot.

Further, in the pots the root weight of complete plants is being compared so it is conceivable that though the weight of roots per plant may be greater with the more frequent cutting the weight per volume of ground may not be greater.

This would go far to explain the disparity which exists between sample weights and the weights of complete plants.

Though this may not be the entire explanation it is evident that some factor is influencing the plots and not the pots which tends to indicate the inadequacy of root studies under the artificial conditions in the pots.

In the mixed plots and pots evidence definitely points to the depressing effect of frequent cutting on total

root weights. In most cases the weights of both ryegrass and clover have been decreased but it is noticeable that in the main much greater reduction is evident in the P. rye than in the clover. This is particularly obvious in the pots where little difference occurs in the clovers. In point of fact little importance can be placed on the clover weights in the 3" mixed plots as these may have contained appreciable amounts of P.rye which it was impossible to separate from the clover.

II. EFFECT OF ONE INCH AND THREE INCH SPACING OF THE PLANTS.

The technique adopted did not prove satisfactory for this investigation due to the inadequacy of the sampling of the 3" plots. As previously outlined, samples from the 3" plots were taken so as to include the whole of one plant and when time permitted a sample was taken on the bare ground between the plants. Whether an average of a sample taken over a plant and one taken between the plants would give a satisfactory indication of the average root intensity over the plot is a moot point and could only be ascertained by further investigation so that the results in detail in the section are of doubtful value and have not been included, though a few general points will be mentioned.

The root weights indicate that there is a considerable increase in weight per unit volume of soil under the plants with a 1" spacing and also indicate that they produced much more herbage per plot than was obtained from the 3" spacing. However, the ratio of roots to herbage and the relative efficiency as regards producing herbage of a given weight of roots from 1" and for 3" spaced plots could not be ascertained.

In P. rye especially there was a much greater weight of root in the 6" to 12" layer from the 1" spacing indicating a better penetration up to 12" though not necessarily of greater depth of penetration.

Assuming that each sample from the plots with plants 1" apart contained the minimum of four plants, the number of tillers per plant in the 3" and inch-spaced plots is 44.7 and 11.7 respectively, the number of roots per plant, 208 and 61.6, and the tiller/root ratio 5.3 and 4.7.

III. EFFECT OF COMBINATION OF P. RYE AND WHITE CLOVER.

The sampling technique adopted here also did not prove satisfactory for this study due to the difficult of separating the P. rye and White Clover roots and the results obtained, therefore, will not be discussed for the purpose of this thesis.

TILLER

IV. SEASONAL VARIATION IN ~~THE~~ NUMBER AND WEIGHT OF ROOTS.

1. P. Rye-grass.

Though there is some discrepancy between the 1" and 3" spaced plots it appears in general that where the plants are spring sown the root weights attain a maximum in January or February, after which the weight falls off (in most cases) to April after which a slight increase is noted until July when the increase is very marked. This rapid increase was evident until November when this trial terminated. There appears some evidence to show that in November the roots tend to decrease in weight These points are shown in Graph 2.

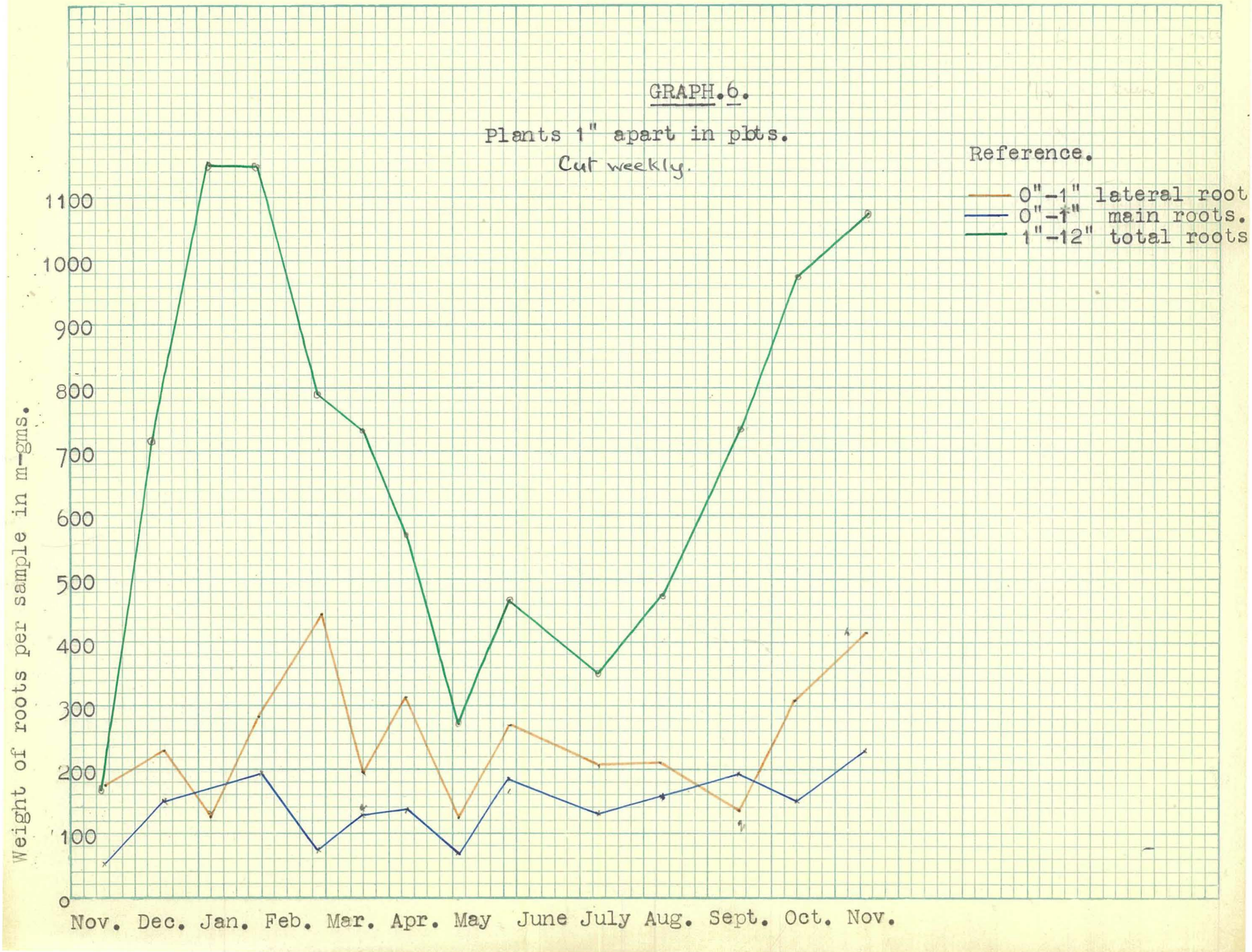
The seasonal trends in the weight of different types of root show much variation. In the 3" plots the laterals in the top inch show an increase from February-March when they remain steady and again increase in July. The main roots show a maximum in February and March and then show a decrease until May which is followed by a marked increase until about July. The roots throughout the top foot follow a similar course to that shown by those in the top inch. See Graphs 8 and 9.

In the 1" plots these trends are not so clear cut and the issue is clouded by considerable variation as can be seen from Graphs 6 and 7.

2. White Clover.

The seasonal variation of root weight in the White Clover strains used is not so marked as in P. rye and tends in some instances to be marked by variation between individual samples. In general (as can be seen from Graphs 5a, b, c and d)

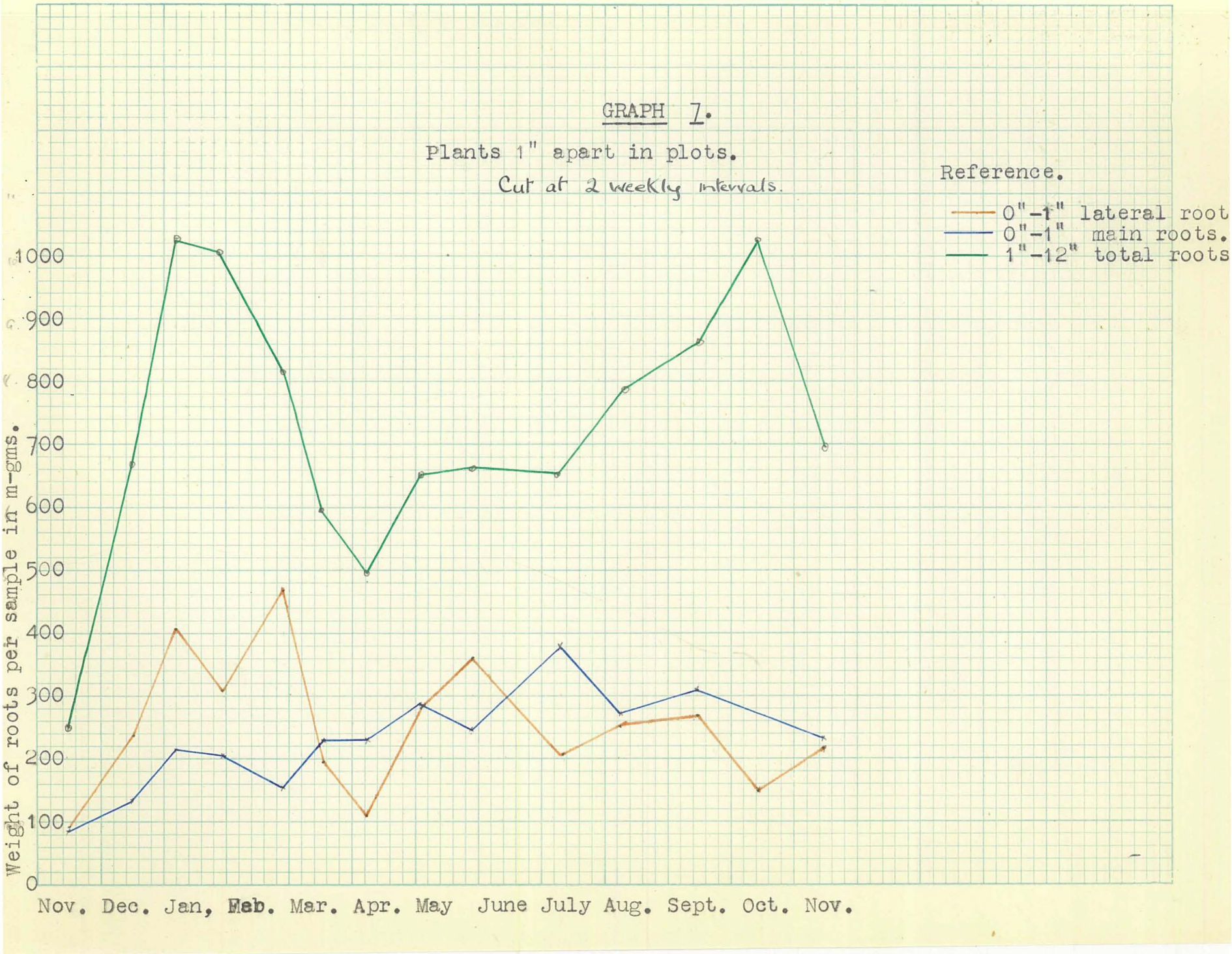
the root weight of spring sown clovers increased to a maximum in February, and then fell off till April, after which a gradual increase took place until August when the increase in root weight became more rapid in most plots. Root activity as indicated by an increase of root weight appears to increase gradually during the season when production of leaf is negligible. There is a more marked activity just prior to active production of herbage.

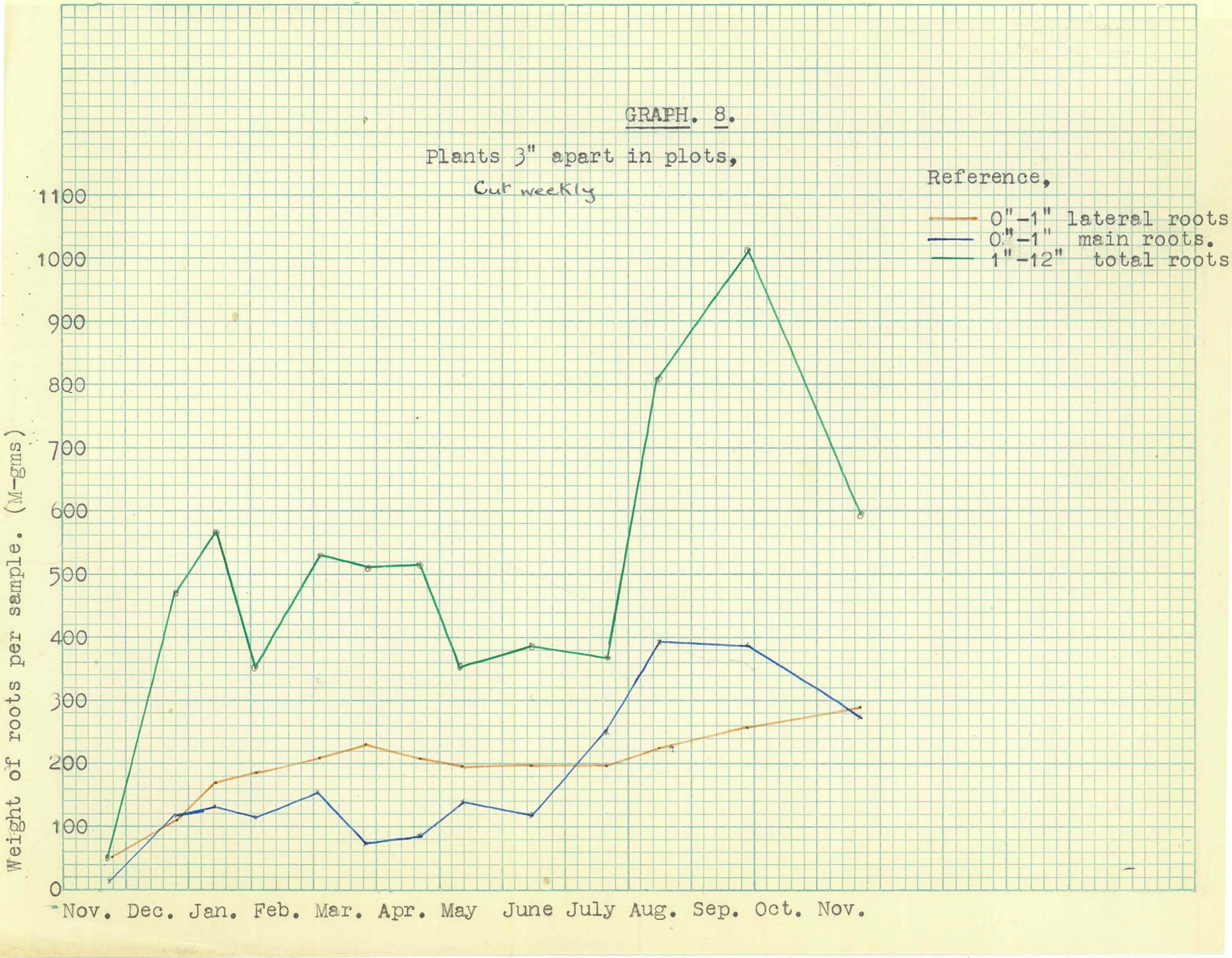

GRAPH.6.
Plants 1" apart in pbts.
Cut weekly.
Reference.
0"-1" lateral root
0"-1" main roots.
1"-12" total roots
Weight of roots per sample in m-gms.
0
100
200
300
400
500
600
700
800
900
1000
1100
Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov.

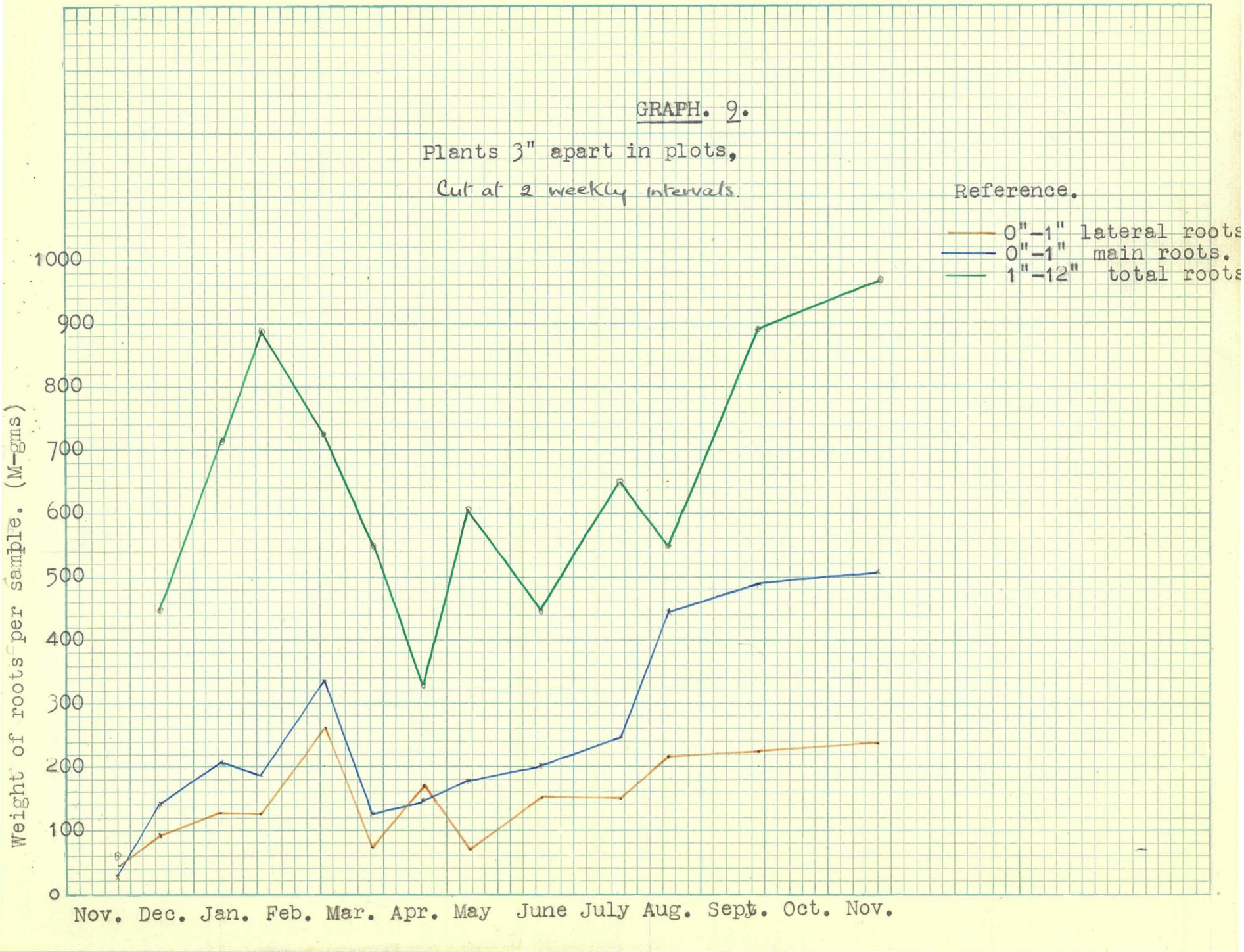
GRAPH 7.

Plants 1" apart in plots.

Cut at 2 weekly intervals.




GRAPH. 8.
Plants 3" apart in plots,
Cut weekly
Reference,
0"-1" lateral roots
0"-1" main roots.
1"-12" total roots
Weight of roots per sample. (M-gms)
0
100
200
300
400
500
600
700
800
900
1000
1100
Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sep. Oct. Nov.


GRAPH. 9.
Plants 3" apart in plots,
Cut at 2 weekly intervals.
Reference.
0"-1" lateral roots
0"-1" main roots.
1"-12" total roots
Weight of roots per sample. (M-gms)
0
100
200
300
400
500
600
700
800
900
1000
Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov.

Discussion of Seasonal Variation in Root Weight.

Perennial Ryegrass.

While the lack of adequate replication gives somewhat undue variations in the weights obtained it is clear that where plants are spring sown root weight is at its greatest in February and falls away until May and the subsequent increase coincides with the commencement of active growth in July.

In view of the fact that the white roots are assumed to be capable of storing food it might reasonably be expected that the building up of reserves corresponds to an increase in the weight of the main root system but this seems doubtful in this instance. Remy (13) in Germany has shown that root reserves in P. rye are built up in Autumn and early winter, a period when, in these trials it is seen the weight of the main root system is low. During this period young white roots were observed, but if they were acting as storage organs the increase in weight due to the reserves is masked by the decrease of weight due to the death of a certain number of roots which occurs at this stage. This indicates the inadequacy of root weights as a basis for root studies.

White Clover.

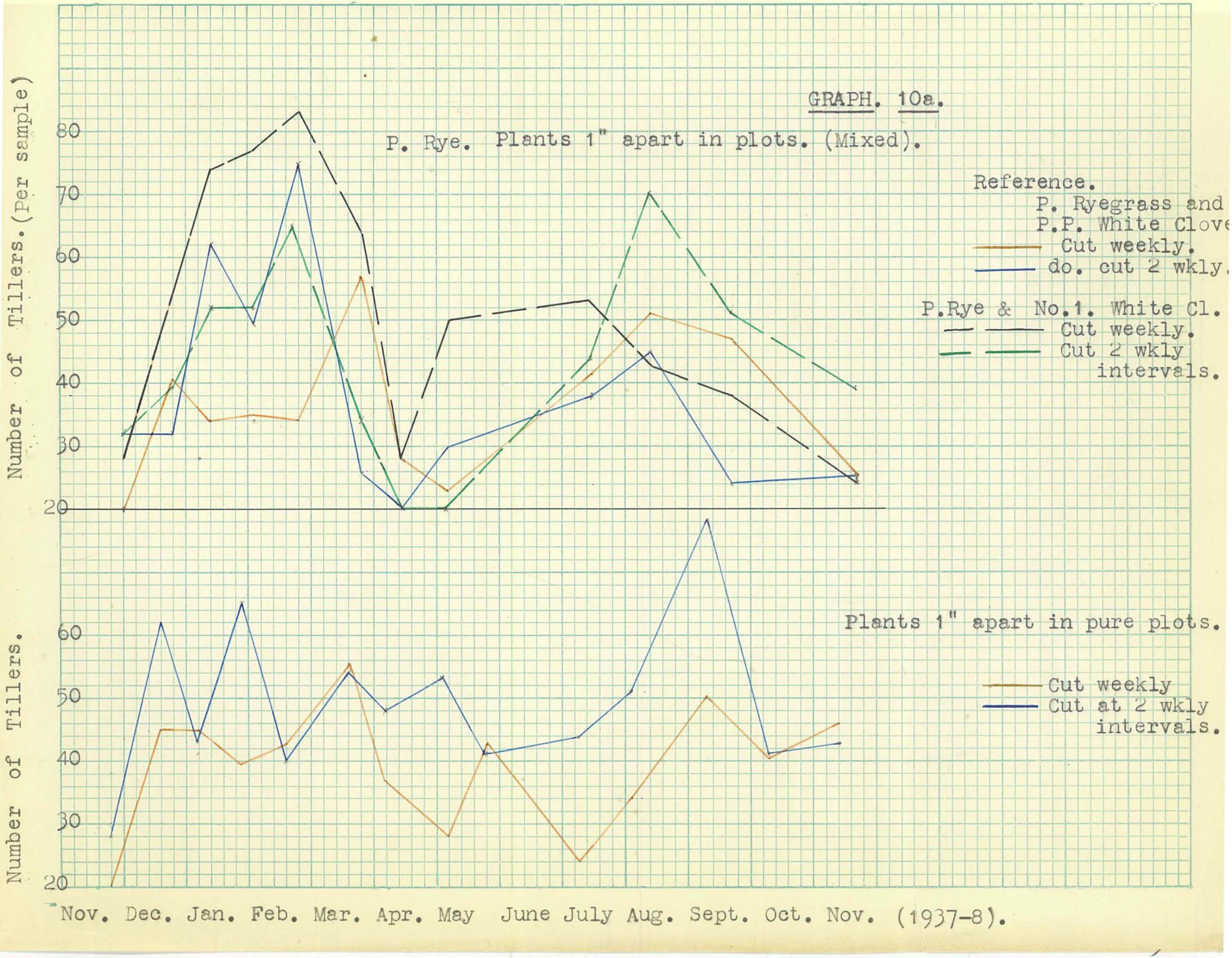
The root weights of clover in the main follow the periods of active growth of foliage, being low during the period of negligible production of leaf. The resumption of root activity as measured by root weight seems to precede the active growth of foliage in early September but this is inconclusive.

3. Seasonal Production of Tillers.

As shown in Graphs 10 a and 10 b, tiller production does not proceed uniformly throughout the season but, under spring sowing, reaches a maximum in February - March, after which numbers fall to a minimum in April. Activity in tiller production commences again in July-August.

This is in agreement with the findings of Robert and Hunt (9) who note a maximum tiller production but do not mention the resumption of growth activity. They postulate that the tillers dry up and slough away or become moist and decay. The presence of moist tillers in an apparent state of decay was noted in these trials on March 10th. and subsequently until June.

GRAPH. 10a.


P. Rye. Plants 1" apart in plots. (Mixed).
Number of Tillers. (Per sample)
80
70
60
50
40
30
20
Reference.
P. Ryegrass and
P.P. White Clove
Cut weekly.
do. cut 2 wkly.
P.Rye & No.1. White Cl.
Cut weekly.
Cut 2 wkly
intervals.
Number of Tillers.
60
50
40
30
20
Plants 1" apart in pure plots.
Cut weekly
Cut at 2 wkly
intervals.
Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. (1937-8).

GRAPH. 10b.


P.Ryegrass plants 3" apart in mixed plots.
Reference.
P.Rye. & P.P. Clover
Cut weekly.
Cut at 2 wkly intervals.
P.Rye & No.1. Clover
Cut weekly.
Cut at 2 wkly intervals.
P.Ryegrass plants 3" apart in pure plots.
Cut weekly.
Cut at 2 wkly intervals.
Number of Tillers (per plant).
Number of Tillers (per plant)
Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. (1937-8)

V. GENERAL OBSERVATIONS ON THE OCCURRENCE OF WHITE CLOVER NODULES.

Results:

Table XXIV summarises the results of the nodule data obtained, while Graphs 11, 12 shows the seasonal variation.

The nodule value shown was obtained by taking the very small nodule as unity, a small one as two units, a medium as three, and a large as four. This assumes that :

4 very small nodules = 1 large nodule.
3 " " " = 1 medium "
2 " " " = 1 small "

The total number of nodules in 12 samples is taken in each case.

This is a purely arbitary means of giving some emphasis to the larger nodules. An involved consideration of the relative volume of the nodules, the relative volume of bacteriodal tissue, and the relative value of the tissue might have given a more accurate factor of 'nodule value' but this still would have been arbitary and for the purpose of this investigation was not considered.

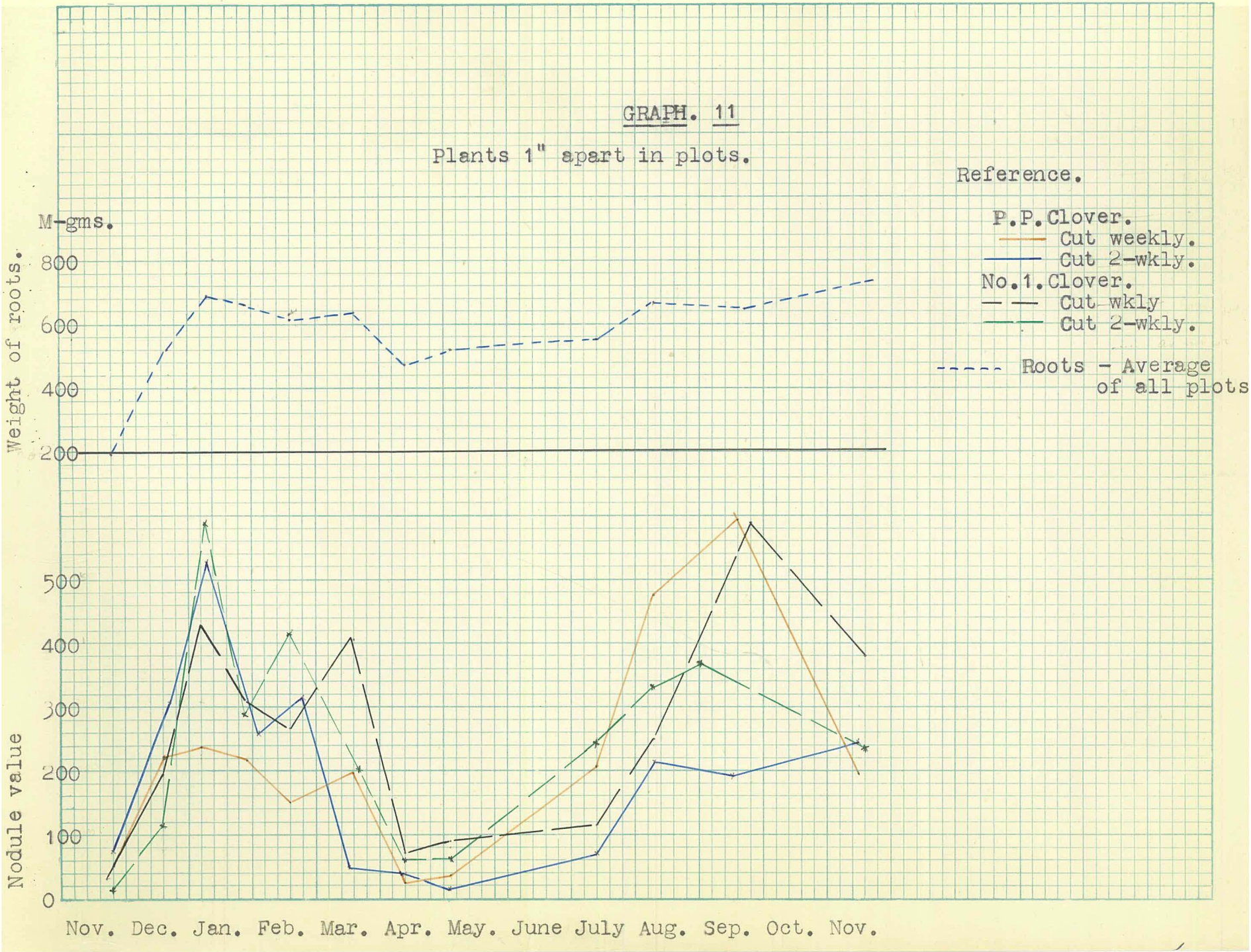
The small number of cases available tends to make any conclusions somewhat conjectural, but the following points seem evident within the limits mentioned.

1. While in the 1" spaced plots there seems to be a reasonable correlation between root weight and 'nodule value' (see Graph 13), in the 3" plots this is less evident.

There appears to be no connection between the nodule value obtained and the production of leaf.

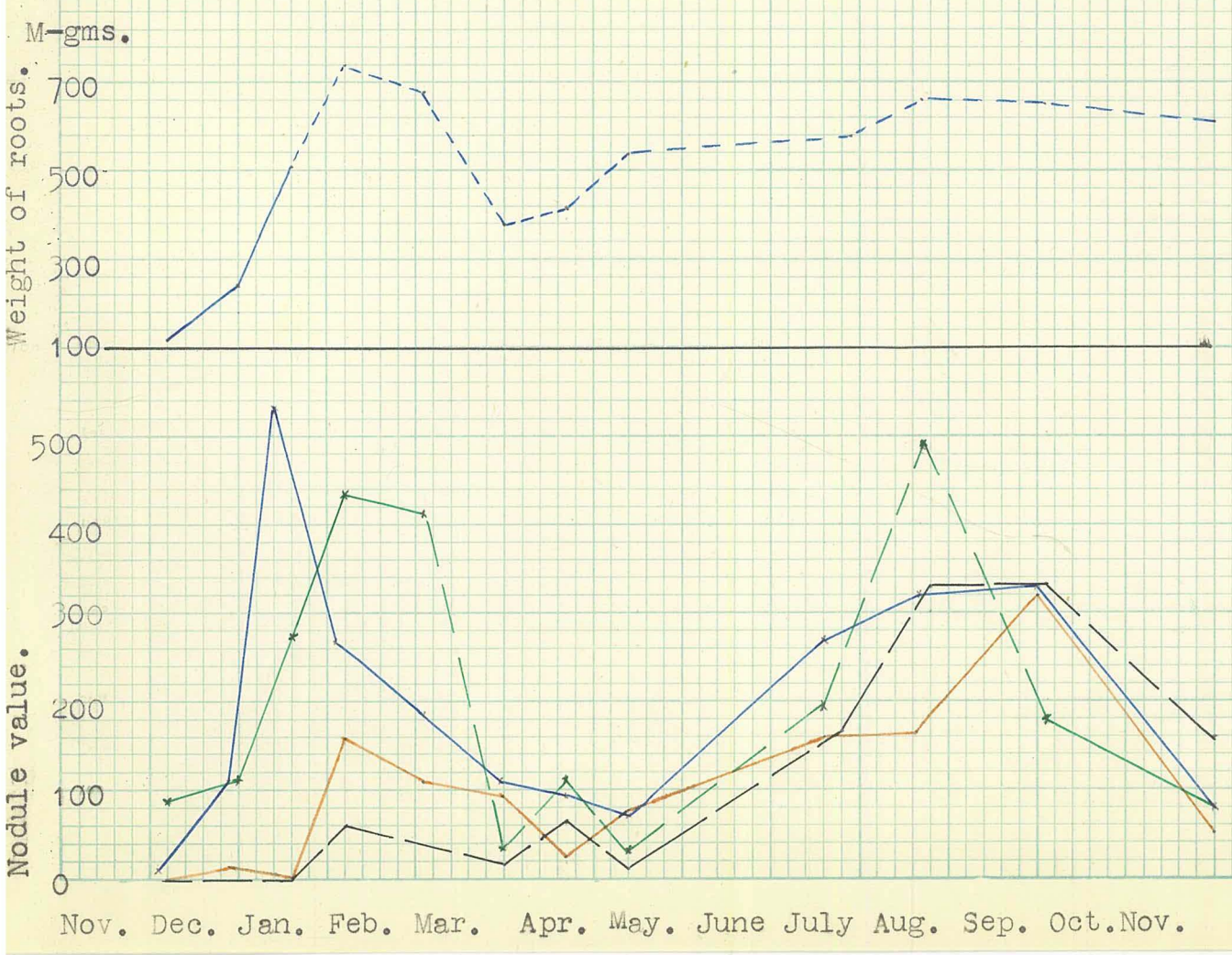
GRAPH. 11

Plants 1" apart in plots.



GRAPH. 12.

Plants 3" apart in plots.



Reference.

P.P. Clover.
Cut weekly.
Cut 2-wkly. intervals.

No.1. Clover.
Cut weekly.
Cut at 2-wkly intervals.

Roots- average of all above plots.

2. The No.1 Clover maitained a consistently higher nodule value than the corresponding P.P. Clover plot.

3. The nodule value attained a maximum in January, a minimum in Winter and increased in September.

Discussion.

Two points stand out in the above results: firstly the fact that the No.1 White Clover has a higher nodule value than P.P. Clover, and secondly the marked seasonal variation of the nodule value.

Lohnis and Fred (16) say that 'the bacteria attack only the new roots'. It can be seen in these trials that the periods of the year when the nodule value is high are the same as those showing rapid new root development and extension. The seasonal variation of nodule formation thus follows closely to the seasonal variation in root weight. See Graph 12, " "

With regard to the greater number of nodules found in the No.1 White Clover, it is shown by Lohnis and Fred (16) that the bacteria present in the vicinity of a root encourage it to proliferate and incorporate them. It seems likely, therefore, that the roots of the stronger growing No.1 Clover are somewhat more active than the P.P. type and so have acquired more nodules. That the No. 1 Clover is stronger growing is born out by the consistently higher root weight of the No.1 Clover.

TABLE XXIV.

Production (Green Weight) From Each Plot and the Total Root Weight and Nodule Value from 12 Samples.

Plants 1" Apart.

Interval of Cutting.	No. 1 Clover (pure). Nodule Value.	Weight Roots m-gms.	Production gms.	P.P. Clover (pure). Nodule Value.	Weight Roots.	Production.
Weekly	3120	7600.4	2928	2584	7058.2	2402
2-Weekly	2901	7231.7	4949	2298	6267.5	2776
	No.1 Clover with P. Rye.			**P.P. Clover with P. Rye.**		
Weekly	414	-	869	613	-	298
2-Weekly	472	-	1021	459	-	845

Plants 3" Apart.

	No. 1 Clover (pure).			P.P. Clover (pure).		
Weekly	1247	6491.6	2536	1166	6319.8	1673
2-Weekly	2505	6395.2	2533	2373	5330.3	1759
	No.1 Clover with P. Rye.			**P.P. Clover with P. Rye.**		
Weekly	2449	7252.8*	624	1579	6881.7*	644
2-Weekly	2086	8722.7*	1174	1732	8331.7*	792

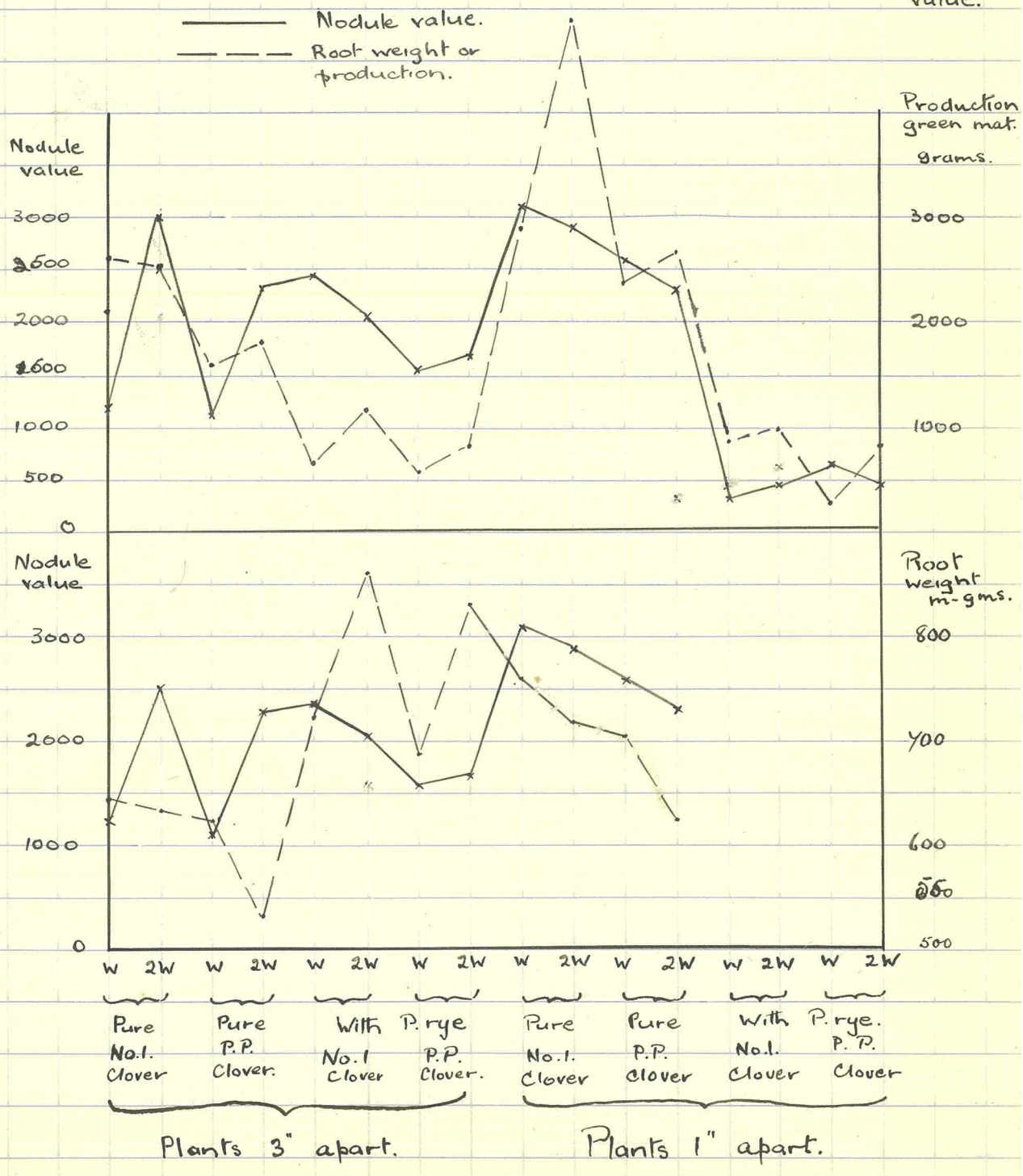
*Of doubtful value due to contamination with P. Rye roots.

GRAPH 13.

Showing

: Top : correlation production green matter and nodule value

lower : correlation root weight and nodule value.



E. CRITICISM OF TECHNIQUE.

I. GENERAL:

The technique used here may be described as an endeavour to study the behaviour of the roots when subjected to various treatments under conditions approximating to natural conditions as opposed to study under the purely artificial conditions set up when pots and/or single plants are used.

The first point that arises is the value of root weight as an indication of root activity. It would appear at first sight that the whole technique is dependent on the validity of root weights as a means of measuring root activity, but in point of fact this is not so.

The writer considers that root weights alone are quite inadequate as a means of studying the root system since a given weight of root may represent an extensive root system or a smaller one in which are stored considerable root reserves. Concerning seasonal trend, evidence obtained in this trial points to the fact that at some periods certain roots may be dying while others are storing reserves. These two factors would act in opposite directions and tend to give no effect on the root weights, and were this being used as a basis for study, two important functions occurring in the roots might not be observed.

It is evident then that other factors will have to be considered in conjunction with the root weights. In this

connection we find various features being used. Parlychenko (3) uses an elaborate method of obtaining root length while Wahlem (14) has used the Specific Gravity of the roots assuming that this gives an indication of the root reserves. Chemical analysis will be of utmost value in certain investigations, while the future may bring to light other methods of measuring root activity.

The point I wish to stress is that whatever the method of study it seems feasible that a suitable source of material and an adequate means of getting representative samples will be a necessary adjunct. Thus the validity or otherwise of root weights does not limit the value of this technique.

TABLE XXV.

Root Weights (in m-gms.) of 4 Samples
Taken at the Same Time From Each of Certain Plots.

Plants 3" Apart.

P. Rye.		No. 1 Clover		P.P. Clover.	
Weekly	2-Weekly	Weekly	2-Weekly	Weekly	2-Weekly
579.0	633.0	648.0	688.0	686.5	352.0
985.8	1181.0	662.0	732.0	564.5	255.0
661.0	657.0	800.0	742.5	595.0	360.5
671.5	722.0	686.3	739.0	435.3	375.0

Plants 1" Apart.

P. Rye.		No. 1 Clover.		P.P. Clover.	
Weekly	2-Weekly	Weekly	2-Weekly	Weekly	2-Weekly.
986.0	1492.8	550.0	278.0	459.0	480.0
701.0	1307.7	585.0	612.0	439.0	411.5
1101.3	1079.5	450.0	770.0	264.0	406.5
891.5	1179.2	725.0	568.0	798.5	331.0

A. THE PLOTS.

Number:

As can be seen from Table XXV the weight of roots in four samples taken at the same time from each of 12 plots varied considerably. Thus in a comparison of say 2 treatments in an experiment of this kind one can expect considerable variation and furthermore, as can be seen from the results, differences between treatments are likely to be small so that to establish a significant difference replication of plots will need to be extensive. It is important to note in this connection that, for comparative purposes the plots should be laid down as nearly as possible under similar conditions (i.e. at the same time). Therefore in view of the fact that one plot 40" x 40" with plants 1" apart took approximately 16 man hours to transplant it is likely that only one point could be under investigation in any one series of plots in which the treatments were adequately replicated. Thus anything in the nature of a factorial design (Yates (15)) would not be feasible unless you had plenty of man hours available.

Size:

This to a large extent must be influenced by the number of samples to be taken. In point of fact for an experiment lasting over a period of 12 months many more samples per plot would be needed than were taken in this experiment so that 40" x 40" would be too small.

Apart from this another factor which is worthy of consideration is the importance of border effect. From figures

and observations given later (q.v. page ??) it is obvious that a 'border' of at least 5" must be allowed. This would represent 44% of a plot 40" x 40" a poor utilisation of the plants indeed. In view of this the possibility of joining 2 or 4 plots into one and giving the halves or quarters respectively the appropriate treatment should be investigated. In 4 plots 40" x 40" with plants 1" apart 2800 plants would be 'wasted' whereas in a plot 80" x 80" only 1500 would not be used.

This assumes no interference at the line dividing the treatments but even allowing some margin the scheme seems worthy of mention. This system should not be incompatable with duplication and statistical design.

B. TRANSPLANTING.

As mentioned on page 10, though transplanting had no visible effect on the rye grass roots it obviously affected the Clover and no doubt influenced root development in both cases. Also it may have had some bearing on the poor establishment of Clover in the mixed 1" spaced plots. In addition transplanting involves much time and labour and some method which satisfactorily obviates it would be a distinct advantage, since more plots could be laid down in a given time.

It might be possible to eliminate transplanting -

(i) through a heavy and even rate of seeding, (ii) by carefully sowing the seed in rows. This method could be used for the mixed plots. Thinning to the correct distance apart would of course, be necessary.

C. SAMPLING.

Frequency of Sampling:

It is evident from this work and that of others mentioned in the text that the root system of grasses is merely transitory. Reserves are, under certain conditions, being built up while at other stages these are being broken down and utilised. The roots themselves are subjected to changes being extended at some periods and replaced at others.

While the extension and replacement may occur at definite periods it is likely that the amount of reserves material will vary considerably over short spaces of time, dependent on treatment given. In view of this I suggest that samples should be taken at weekly or fortnightly intervals and that samples from various plots which are to be compared should be taken as nearly as possible at the same time.

Number of Samples:

Whatever the method of studying the root system it will probably involve the use of several plants subjected to the same treatment which will be examined at successive stages of growth. Since the various plants will vary (note variation of 3" spaced rye grass and clovers in Table xxv) a considerable degree of variation must be expected in this method.

As can be seen from figures for sets of 4 samples taken at the same time from certain of the 1" apart plots (See Table XXV) considerable variation occurs in root development over the plots even though these were apparently uniform as judged by the growth of the tops.

This being so it is evident that one sample per plot at each sampling is inadequate and that 3 and possibly 4 samples would be necessary to give an average figure which would be a reliable indication of the condition of the roots at a given time.

Sprague (4) has used a method whereby he takes a sample 7" x 3" and 12" deep and from this cuts duplicate samples 3" x 1" x 9" deep. From the experience of the above I should think that this method is hardly satisfactory, since the samples are small though the idea of duplicates has much to commend it.

Errors in Sampling:

Under this heading some sources of error will be mentioned which occur even assuming the plots are uniform as regards their root systems.

In the 1" apart plots any number of plants from 4 to 9 can be obtained in a sample. (See Fig.15). Further, due to the fact that the plants tend to lose their original lines it is not possible to include any definite number of plants in any particular sample. Also it is difficult to count the number of plants per sample after washing due to the sectioning and mutilation of some of the plants during sampling, and even assuming the number of plants could be counted it is doubtful if a satisfactory factor could be introduced to allow for the varying number of plants per sample since slight variations in the position of the sampler would result in different proportions of the roots of certain of the plants being obtained.

In order to mitigate this source of error it is likely that several samples would have to be taken. Just how many would be necessary is a matter that would need to be ascertained. In an effort to overcome this tiller number was taken as a basis.

Another point worthy of mention is that the main difference due to the varying number of plants is likely to occur in the top inch and in some investigations this region might be discarded in which case the lower layers may not vary so much. Sprague (4) has found a correlation between the layers 1 - 9" and the total weight of roots, i.e. including the 0 - 1" layer. This, however, would need verification, and is merely mentioned as a possibility as a basis for future investigation.

Another difficulty that has arisen in this experiment with the 3" spaced plants and would occur also with 2" spacing, is to get an idea of the condition of the roots over the whole of the plot. A sample can be taken over a plant or on bare ground between the plants and the obvious method would appear to be to take a sample in each position and average the figures. This, however, would seem to have serious limitations and the value of such an average for comparison with a sample from an inch apart plot would seem very doubtful.

Assuming it was satisfactory other errors are involved. A slight difference in the position of the sampler over the plant and on the bare ground would give a different root weight. Also a slight deviation from the perpendicular of the sampler would produce a similar effect. In addition replication say 3 times would

involve taking 6 samples in the pure plots with plants spaced at 3" while in the mixed plots on the above plan 12 samples would be necessary possibly without giving sufficient accuracy for most comparisons.

Another error that occurs is sampling in dry as opposed to wet ground. It takes considerable effort to get the sampler into the ground so that the wet soil is compressed which gives in effect 12" + x" in the sample. It has been noted while sampling wet soil that the level of the soil in the sampler was 1" lower than the normal soil level which means that 13" have been compressed into the 12".

This could probably be overcome to a large extent by an alteration in the construction of the sampler. It would be feasible to reduce the thickness of the material by using a better steel and the lugs could be reduced in size.

This would reduce the resistance of the sampler when driving it into the ground and would assist in reducing the error mentioned above.

D. LABORATORY TREATMENT.

Cuting into 1" layers. This is probably the source of some error, especially near the surface where there is a considerable development of roots. It is often difficult to be sure just where the surface of the soil definitely is due to distortion when the sampler is being driven in, and any error in the first inch is carried through the depth of the sample. If the samples were replicated a fairly reliable average figure could be obtained. This would also apply where a stone of say $\frac{3}{4}$"

diameter or larger has been found in any particular layer as was sometimes the case in this experiment.

Washing the Roots:

To get the roots reasonably free of soil involves washing so intensely that much loss of the finer root and root hairs must occur. Rose, in unpublished work, found that in washing a one foot ryegrass sample through the sieve 20 times approximately 20% of the total weight of roots passed through the sieve and was collected in a muslin 'baffle'. A closer examination revealed a large amount of organic matter and soil particles which could not satisfactorily be separated from the roots. Thus it would seem that 10 -15% might represent the loss from an ordinary sample washed by one inch layers through the sieve. While losses from all samples would tend to be similar those with the greater amount of fine root material would be unduly affected.

Losses from Clover samples would probably be considerably less than those from the ryegrass since Clover does not have such a large proportion of fine roots.

However, the method of washing would appear to need revision and an improvement could probably be affected by using a finer sieve and soaking the sample till the soil and roots formed a thin layer on the bottom of the sieve when the roots could be separated with the aid of forceps.

Organic matter such as decaying leaves, needles from adjacent pine trees and the like present a difficult in the first inch layer, as it is extremely difficult to separate the finer roots from this foreign material. Could the first inch

be disregarded along the lines suggested (q.v. page 72) this difficulty would be overcome.

Post mortem changes in the roots are of doubtful significance but it would be desirable to complete the examination of the roots as soon as possible after harvesting.

Weighing the roots has been dealt with under a separate heading (page 25). The technique adopted should be satisfactory.

E. THE POTS

Certain discrepancies have been observed between the results from the plots and the pots. The most serious of these was seen in the different effects of defoliation on clover roots under both 1" and 3" spacing where the plots indicated a decrease in root weight under the more lenient cutting and the pots showed an increase. While these results may be fortuitous, they lend weight to the view that root studies would be better carried out under the more natural plot conditions as opposed to studies in pots which introduce artifical conditions and tend to give resul which are of doubtful practical application.

One difficulty encountered in the use of pots in this experiment can be mentioned here. The error was introduced when comparing the root weights of plants under weekly cutting and cutting at two-weekly intervals. The plants were 1" apart and under weekly cutting some died out, whereas under the two-weekly cutting they were able to survive. Consequently there was reduced root competition in the pots cut weekly and the plants

which did survive were able, in spite of the more frequent cutting, to develop a heavier root system than the plants in the pots cut at two-weekly intervals. However, the root weight per unit volume of soil (i.e. as taken in the sampler from the plots) was not so great under the more frequent cutting. Replication of pots is necessary as with the samples.

F. CONCLUSIONS.

From the results it is apparent that the differences due to treatments are likely to be small while the variation between the samples is likely to be considerable. This will necessitate replication of plots and samples and the large number of samples likely to be involved in an experiment will tend to make the technique somewhat unweildy in practice. In addition the method is not readily amenable to the study of deep rooting plants, or to the study of plants spaced widely apart.

Nevertheless, the system provides a rapid means of quantitative study and seems to have definite value in tracing the seasonal growing cycle and as a means of obtaining material for chemical studies of root reserves.

Indications are that further investigation using adequately replicated plots and samples is necessary.

II. BORDER EFFECT.

Since this factor is obviously of importance in a technique using small plots some investigation is warranted.

In the 3" plots the two outer rows of plants were allowed for border effect and were found to be quite sufficient since inside of these no border effect was visible and root samples taken revealed no differences which could be attributed to this between the root weights of plants. No doubt in the clover plots as the clover came to cover the ground by virtue of its runners edge effect might assume importance but that possibility did not arise in this experiment since the ground had not become covered.

The position in the 1" plots was quite different, however, The plants were obviously closer than the optimum distance for satisfactory growth and competition was an important factor, and in the P. rye plots it soon became evident that the 2" allowed was totally inadequate to obviate the effect of the 'border'. (See Fig. 22). In the 1" Clover plots no 'border' was visible in the tops though it was suspected it might be affecting the roots.

For this reason all samples in the 1" spaced plots were taken at least 6" from the edge.

To ascertain the influence on the roots of this 'border' four samples were taken in the positions shown in Fig. 23. One was taken just outside the plot, one near the edge, one 2½" to 5" from the edge and one 5" to 7" from the edge. Four sets of samples were taken from each of a clover and a P. Rye plot at 3"

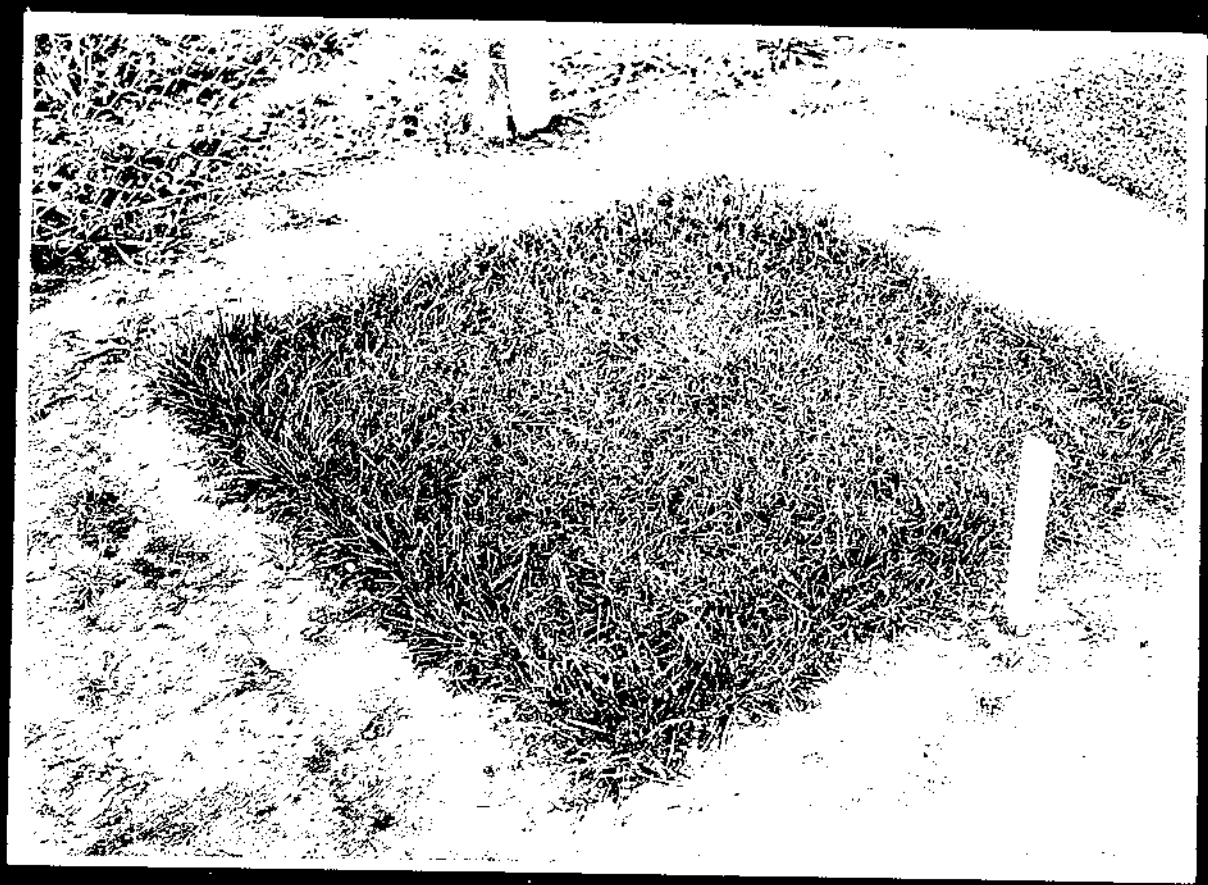


FIG. 28. Border effect in pure rye grass plot with plants one inch apart.

Photo by Harvey Drake.

and 1" spacing. As mentioned, no effect was observed in the 3" plot but the results from the 1" plot are given in Table XXVI.

TABLE XXVI.

WEIGHT ROOTS PER SAMPLE (in m - gms.)

(Position Samples shown in Fig. 23.).

Plants 1" Apart.

	P. RYEGRASS.					NO.1 CLOVER.			
Position	Set 1	Set 2	Set 3	Set 4	Position	Set 1	Set 2	Set 3	Set 4.
A	182.0	180.8	178.0	184.3	A	14.5	14.0	13.4	14.3
B	2035.0	1435.3	1818.0	2483.0	B	810.3	524.5	662.5	702.8
C	893.0	1015.0	1470.5	1768.8	C	640.3	605.1	577.0	725.0
D	1895.0	1249.0	1640.0	2157.0	D	688.5	567.8	601.8	668.0
	Average for plot at date sampling			1830.0		Average for plot at time sampling			613.0 m-gms.

From Table XXVI it can be seen that in the P. ryegrass plot the samples near the edge showed a greater root weight than in the main part of the plot while further in $2\frac{1}{2}$" to 5" there was a falling off in root weight, at $5\frac{1}{2}$" to 7" the samples proved similar to those in the main part of the plot within the limits of sampling error, and one might conclude the border was having no effect further in than 5" - 6".

The position appears to be as follows. In the ryegrass plot competition was a very important factor, the plants being

only 1" apart, and this effect of competition would be intensified by the natural tendency of the ryegrass root system to spread laterally. Thus the outside 2" to 3" grew vigorously as competition was confined to one side only and consequently the root system became well developed. The lateral spread is obvious from the relatively high weight of roots in the samples taken just outside the plot. Then at 3 - 5" the plants, and their root systems, were unthrifty due to the more extensive competition from the vigorous 'border'. Further in than 5" the plot was normal.

The clovers gave no visible border effect, the foliage appearing quite even from the edge inwards. Nevertheless figures in Table XXVI would indicate the advisability of allowing at least 6" for border effect. That the border effect was much less pronounced than in the rye-grass can be explained to some extent by the fact that the clover roots tend to go straight down and have a very slight lateral spread. This feature is obvious from profile studies and also from the fact that there was a very low weight of roots in the samples taken outside the plot. For this reason the absence of competition outside the plot would tend to have less significance in clover than in the case of the P. rye-grass plots.

F. SUMMARY AND CONCLUSIONS:

1. Some limitations of the technique have been pointed out and the necessity for replication of plots and samples stressed. The main disadvantages of the technique are that it is not amenable to the study of root systems of plants spaced at distances greater than 1" or to the study of deep rooting plants. It is valuable in the study of the seasonal growing cycle and as a means of obtaining representative material for chemical analysis.

Some criticisms of pots studies have been mentioned.

2. While the effect of more frequent defoliation is to reduce tiller number the possibility of increasing the numbers of a vigorous certified strain of P. rye is postulated. The root weight of P. ryegrass was decreased under the more frequent defoliation.

The root weights in the pure clover plots under frequent defoliation were greater than under less frequent defoliation. This was not confirmed by pot studies.

3. The greater root weight and better penetration in the 1" spaced plots was noted, as compared with 3" spacing.

4. The seasonal variations in root weights have been traced and in general increases in root weight appear likely to indicate an increase in root length rather than an increase in the reserves stored.

The seasonal variation of tillers was also traced.

5. Correlation between root weights and nodule numbers was not definitely established. The seasonal variation appears likely to correspond with root activity as measured by increase in root weight.

The more vigorous certified No.1 White Clover (which produced more herbage than the certified P.P. type) showed a consistently greater number of nodules than the P.P. type.

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APPENDIX A (Contd.)

No. 1 White Clover in pure plots. Plants 1" apart.

Root weights in m - gms per sample and dates of sampling.

Dates of Sampling.	Cut at weekly intervals.	Cut at 2 weekly intervals.
Nov. 26, 1937	142.3	187.1
Dec. 21.	530.7	488.5
Jan. 7, 1938	785.9	661.6
28	631.3	625.0
Feb. 18	618.3	595.7
Mar. 18	763.0	736.6
Apr. 12	514.0	604.0
May 4	645.1	673.5
July 12	505.3	499.3
Aug. 10	919.4	752.5
Sept. 21	752.5	695.6
Nov. 20	792.6	712.3
Total	7600.4	7231.7

APPENDIX A (Contd.)

No. 1 White Clover in pure plots. Plants 3" apart.

Root weights in m - gms per sample and dates of sampling.

Date of Sampling.	Cut at weekly intervals.	Cut at 2 weekly intervals.
Dec. 7, 1937	133.7	185.4
30	254.9	311.8
Jan. 19, 1938	370.4	544.9
Feb. 8	904.6	864.3
Mar. 4	827.6	846.7
31	519.7	211.5
Apr. 20	483.3	429.3
May 12	247.0	503.5
July 26	487.1	500.9
Aug. 22	699.5	786.5
Oct. 3	757.5	608.1
Nov. 24	806.3	602.3
Total	6491.6	6395.2

APPENDIX A. (Contd.)

P.P. White Clover in pure plots. Plants 1" apart.

Root weights in m - gms per sample and date of sampling.

Date of sampling	Cut at weekly intervals	Cut at 2 weekly intervals
Nov. 27, 1937	237.4	206.7
Dec. 17	661.6	408.9
Jan. 7, 1938	654.6	642.2
28	691.8	711.9
Feb. 18	611.6	641.2
Mar. 18	634.1	394.4
Apr. 12	395.1	385.2
May 3	450.5	328.0
July 12	581.8	622.6
Aug. 9	577.5	532.3
Sept.20	684.1	455.4
Nov. 16	578.1	858.7
Total	6758.2	6187.5

APPENDIX A (Contd.)

P.P. White Clover in pure plots. Plants 3" apart.

Root weights in m - gms (per sample) dates of sampling.

Dates of Sampling	Cut at weekly intervals	Cut at 2 weekly intervals.
Dec. 6th. 1937	71.8	69.1
28	170.0	216.2
Jan.19th. 1938	521.7	597.7
Feb. 8th.	671.9	537.0
Mar. 4th.	530.4	509.7
Mar. 31st.	394.6	389.1
Apr. 20th.	418.3	347.5
May 12th.	867.4	529.0
July 25th.	771.8	545.5
Aug. 17th.	765.3	413.0
Sept.30th.	576.9	676.8
Nov. 18th.	559.7	499.7
TOTAL	6319.8	5330.3

APPENDIX B. (Contd.)

P. Ryegrass in pure plots — Plants 1" apart.

Number of tillers and roots per sample and ratio tillers to roots and dates of sampling.

Date of Sampling	Cut at weekly intervals			Cut at 2 weekly intervals		
	No. of Tillers	No. of Roots	Rates T/R	No. of Tillers	No. of Roots	Rates T/R
Nov. 18, 1937	19	40	1:2.1	28	76	1:2.6
Dec. 16	45	129	1:2.8	62	145	1:2.3
Jan. 6, 1938	45	122	1:2.7	43	143	1:3.3
28	39	130	1:3.3	65	190	1:2.9
Feb. 18	43	204	1:4.7	40	107	1:2.7
Mar. 17	55	247	1:4.5	54	232	1:4.2
Apr. 8	36	214	1:5.8	48	288	1:6.0
May 3	28	131	1:4.7	53	314	1:5.9
May 25	39	328	1:6.1	54	369	1:6.9
	42	283	1:6.7	54	360	1:6.7
	32	193	1:6.0	40	269	1:6.7
	58	390	1:6.8	16	116	1:7.3
July 7	24	189	1:7.9	44	490	1:11.1
Aug. 4	34	292	1:8.6	51	327	1:6.4
Sept.15	50	236	1:4.7	78	341	1:4.4
Oct. 13	41	255	1:6.2	41	255	1:6.2
Nov. 18	46	324	1:7.0	43	241	1:5.6

APPENDIX B.

P. Rye in pure plots Plants 3" apart.

Number of tillers and roots per sample and ratio of tillers to roots and dates of sampling.

Date of Sampling	Cut at weekly intervals			Cut at 2 weekly intervals		
	No. of Tillers	No. of Roots	Rates T/R	No. of Tillers	No. of Roots	Rates T/R
Nov. 25, 1937	9	16	1:1.8	7	22	1:3.1
Dec. 26	59	156	1:2.6	46	121	1:2.6
Jan. 13, 1938	71	81	1:1.1	47	132	1:2.8
Feb. 3	50	102	1:2.0	37	101	1:2.7
Mar. 2	102	183	1:1.8	58	235	1:4.0
25	38	119	1:3.1	45	166	1:3.7
Apr. 20	32	181	1:5.7	22	173	1:7.9
May 11	35	180	1:5.1	25	239	1:9.7
June 15	25	134	1:5.4	21	125	1:6.0
	33	215	1:6.5	44	248	1:5.6
	47	249	1:5.3	24	161	1:6.7
	26	205	1:7.9	30	156	1:5.2
July 22	63	278	1:4.4	29	225	1:7.8
Aug. 18	97	510	1:5.3	57	310	1:5.4
Sept. 28	73	549	1:7.5	47	409	1:8.7
Nov. 16	68	381	1:5.6	62	465	1:7.5

APPENDIX B. (Contd.)

P. Rye with No. White Clover in mixed plots. Plants 1" apart.

Number of tillers and roots per sample and ratio of tillers to roots and date of sampling.

Date of Sampling.	Cut at weekly intervals.			Cut at 2 weekly intervals.		
	No. of Tillers	No.of Roots	Rates T/R	No. of Tillers	No.of Roots	Rates T/R
Nov. 30, 1937	28	53	1:1.9	15	41	1:2.7
Dec. 24,	39	103	1:2.6	39	107	1:2.7
Jan. 12, 1938	74	175	1:2.4	52	140	1:2.7
Feb. 3	77	157	1:2.0	52	128	1:2.5
Feb. 24	83	211	1:2.5	65	168	1:2.6
Mar. 23	64	170	1:2.7	34	140	1:4.1
Apr. 16	28	113	1:4.0	20	90	1:4.5
May 5	50	174	1:3.5	20	172	1:8.6
July 16	53	294	1:5.5	44	185	1:4.2
Aug. 16	43	248	1:5.8	70	327	1:4.7
Sept.26	38	242	1:6.4	51	349	1:6.8
Nov. 23	24	146	1:6.1	39	178	1:4.6

APPENDIX B. (Contd.)

P. Rye with No. 1 White Clover (mixed Plots) Plants 3" apart.

Number of tillers and roots per sample and ratio tillers to roots and date of sampling.

Date of sampling.	Cut at weekly intervals.			Cut at 2 weekly intervals		
	No. of Tillers	No.of Roots	Ratio T/R	No. of Tillers	No.of Roots	Ratio T/R
Dec. 14, 1937	34	55	1:1.6	64	88	1:1.4
Jan. 5, 1938	59	127	1:2.2	64	122	1:1.7
26	59	152	1:2.6	43	98	1:2.3
Feb. 14	79	195	1:2.5	33	83	1:2.5
Mar. 15	62	161	1:2.6	72	336	1:4.6
Apr. 5	88	275	1:3.1	61	168	1:2.8
29	20	42	1:2.1	53	411	1:7.8
May 20	39	240	1:6.2	52	318	1:6.1
Aug. 4	48	374	1:7.6	55	327	1:5.9
Sept. 2	64	426	1:6.7	50	236	1:4.7
Oct. 11	51	357	1:7.0	97	788	1:8.1
Dec. 16	85	294	1:3.5	84	238	1:2.8

APPENDIX B. (Contd.)

P. Rye with P.P. White Clover in mixed plots. Plants 1" apart.

Number of tillers and roots per sample and ratio tillers to roots and dates of sampling.

Date of Sampling.	Cut at weekly intervals			Cut at 2 weekly intervals.		
	No. of Tillers	No. of Roots	Rates T/R	No. of Tillers	No.of Roots	Rates T/R
Nov. 30, 1937	18	55	1:3.0	32	71	1:2.2
Dec. 24	41	106	1:2.6	31	79	1:2.5
Jan. 12, 1938	34	80	1:2.4	62	168	1:2.7
Feb. 2	35	109	1:2.6	49	121	1:2.5
Feb. 24	34	133	1:3.0	75	247	1:3.3
Mar. 23	57	269	1:4.7	26	120	1:4.6
Apr. 14	28	127	1:4.5	19	86	1:4.5
May 5	23	152	1:6.6	30	295	1:9.8
July 14	41	250	1:6.1	38	159	1:4.2
Aug. 12	51	260	1:5.1	45	248	1:5.5
Sept.22	47	301	1:6.4	24	178	1:7.4
Nov. 22	25	179	1:7.2	21	142	1:6.8

APPENDIX B. (Contd.)

P. Rye with P.P. White Clover in mixed plots. Plants 3" apart.

Number of Tillers and roots per sample and ratio of tillers to roots.

Date of sampling.	Cut at weekly intervals.			Cut at 2 weekly intervals		
	No. of Tillers	No. of Roots	Rates T/R	No. of Tillers	No. of Roots	Rates T/R
Dec. 8th. 1937	43	64	1:1.5	53	86	1:1.6
30th.	44	95	1:2.2	64	136	1:2.1
Jan. 20th. 1938	52	95	1:2.5	107	267	1:2.5
Feb. 9th.	108	239	1:2.2	39	113	1:3.1
Mar. 9th.	66	173	1:2.6	71	319	1:4.0
Apr. 18th.	119	354	1:3.0	34	185	1:5.4
26th.	55	291	1:5.3	78	244	1:3.1
May 16th.	36	159	1:4.4	35	225	1:6.4
July 28th.	95	385	1:4.1	40	321	1:8.0
Aug. 23rd.	54	384	1:7.1	65	232	1:3.6
Oct. 4th.	80	422	1:5.3	61	319	1:5.2
Dec. 1st.	33	181	1:5.7	67	169	1:2.5

APPENDIX C.

NUMBERS OF NODULES PER SAMPLE. NO. 1 WHITE CLOVER 3" PLOTS.

WEEKLY

Date	Very Small	Small	Med.	Lge.	Nodule Value
Dec. 7	-	-	-	-	-
30	-	-	-	-	-
Jan.19	-	-	-	-	-
Feb. 8	6	11	9	1	59
Mar. 4	102	4	-	-	110
31	-	7	1	-	17
Apr.20	-	9	8	5	62
May 12	3	2	1	-	10
Jly.26	26	47	15	-	165
Aug.22	32	67	54	1	332
Oct. 3	4	46	80	-	336
Nov.30	6	20	35	1	156
					1247

2 WEEKLY

Date	Very Small	Small	Med.	Lge.	Nodule Value
Dec. 7	5	27	9	-	86
29	5	23	22	13	169
Jan.19	21	61	24	15	275
Feb. 9	136	75	25	19	437
Mar. 3	150	59	18	23	414
31	-	5	6	2	36
Apr.21	94	3	2	1	110
May 12	1	5	9	-	34
Jly.26	36	67	9	-	197
Aug.22	19	47	125	-	488
Oct. 4	-	13	51	-	179
Nov.30	-	10	23	-	89
					2514

APPENDIX C.

NUMBERS OF NODULES PER SAMPLE. No. 1 WHITE CLOVER 1" PLOTS.

WEEKLY

Date	Very Small	Small	Med.	Lge.	Nodule Value
Nov.26	-	10	3	-	29
Dec.21	9	13	22	23	193
Jan. 7	70	62	52	19	426
28	27	55	37	16	312
Feb.18	142	23	13	10	267
Mar.18	15	66	69	12	402
Apr.13	3	17	11	-	70
May 4	1	16	12	5	89
Jly.13	10	53	-	-	116
Aug.10	21	54	34	4	247
Sept.21	9	60	151	2	590
Nov.18	2	38	99	1	379
					3120

2 WEEKLY

Date	Very Small	Small	Med.	Lge.	Nodule Value
Nov.26	-	6	1	-	15
Dec.17	16	5	16	11	118
Jan. 7	57	112	83	13	582
28	24	60	36	8	284
Feb.18	158	72	31	5	415
Mar.21	132	18	4	5	200
Apr.13	-	5	12	3	58
May 4	2	4	16	-	58
Jly.13	61	90	-	-	241
Aug.10	70	72	36	2	330
Sep.21	19	83	58	2	367
Nov.18	6	28	57	-	233
					2901

APPENDIX C.

WHITE CLOVER 1" WEEKLY

Date	Very Small	Small	Med.	Lge.	Nodule Value
Nov.27	1	16	6	-	51
Dec.17	20	19	20	26	222
Jan. 7	9	20	29	25	236
28	4	18	32	20	216
Feb.18	9	22	13	15	152
Mar.18	27	15	34	8	191
Apr.13	3	4	2	1	21
May 3	-	3	6	2	32
Jly.12	58	69	1	1	203
Aug. 9	83	133	40	1	473
Sep.20	30	52	151	1	591
Nov.16	13	29	39	2	196
					2584

P.P. WHITE CLOVER 1" - 2 WEEKLY

Date	Very Small	Small	Med.	Lge.	Nodule Value
Nov.28	35	14	4	-	75
Dec.21	185	24	10	11	307
Jan.10	116	65	47	34	523
Feb. 2	150	17	6	14	258
24	150	48	19	3	315
Mar.21	10	6	3	4	47
Apr.13	5	7	3	1	32
May 3	8	1	1	1	17
Jly.12	16	21	4	-	70
Aug. 9	33	49	27	-	212
Sep.20		8	60	-	196
Nov.16	2	13	70	2	246
					2298

APPENDIX C.

NODULE NUMBERS PER SAMPLE P.P. WHITE CLOVER PLANTS 3" APART

WEEKLY CUT						2 WEEKLY CUT					
Date	Very Small	Small	Med.	Lge.	Nodule Value	Date	Very Small	Small	Med.	Lge.	Nodule Value
Dec. 6	-	-	-	-	-	Dec. 2	-	1	1	1	9
28	-	2	2	1	14	28	1	16	23	1	106
Jan.19	-	-	-	-		Jan.14	102	116	45	16	533
Feb. 8	124	-	-	8	156	Feb. 3	43	58	32	3	267
Mar. 4	28	31	4	2	110	Mar. 3	140	14	3	2	185
" 31	19	16	8	4	91	" 31	4	34	10	2	110
Apr.21	2	8	2	-	24	Apr.21	3	34	4	3	95
May 12	10	12	13	1	77	May 12	9	7	15	2	76
July 25	13	28	29	1	160	Jly.25	8	75	26	8	268
Aug.19	9	40	25	-	164	Aug.19	27	84	40	1	319
Sep.30	12	40	76	-	320	Sep.30	21	65	56	2	327
Nov.29	2	3	14	-	50	Nov.29	6	-	24	-	78
					1166						2273

APPENDIX D.

Showing Weight Roots in 12 Samples from P.P. Clover Plots

Plants 3" Apart

Cut at Weekly Intervals	Cut at 2-weekly Intervals
170.0	216.2
521.7	597.7
671.9	537.0
530.4	509.7
394.6	389.1
418.3	347.5
867.4	529.0
771.8	545.5
765.3	413.0
576.9	676.8
559.7	499.7
6248.0	5261.2

STATISTICAL ANALYSIS

		d	d^2
1700	2162	+462	
5217	5977	+760	
6719	5370	-1349	
5304	5097	- 207	
3946	3891	- 55	
4183	3475	- 708	
8674	5290	-3384	
7718	5455	-2263	

STATISTICAL ANALYSIS (Contd.)

			d	d^2
	7653	4130	-3523	
	5769	6768	+ 999	
	5579	4997	- 600	
	62480	52612	-12089	33500138
			+ 2221	8852494.86
Av.	5680.0	4782.909	- 9868	
			Av. - 897.091	24647643.14

$$= \frac{24647643.14}{11}$$

$$= 1496.895$$

$$\underline{897.091}$$

$$= 1496.895$$

$$= 0.599$$

Odds 22 : 1

not significant.