A STUDY OF THE EARLY DEVELOPMENT OF

THE ROOT SYSTEMS OF VARIOUS

GRASS SPECIES;

AND

A STUDY OF THE IMPORTANCE OF VARIOUS

ROOTS, PARTICULARLY THE SEMINAL

ROOTS, TO LOLIUM PERENNE.

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SECTION I.

INTRODUCTION.

New Zealand is essentially a land of pastures. Greater reliance is placed on pastures for the sustenance of stock by the farmer in New Zealand than probably anywhere else in the World. The study of pastures is therefore of paramount importance to the national welfare of New Zealand and their improvement will be reflected in raised living standards and at the same time will provide more food for the hungry world of today.

There is no doubt that New Zealand is favoured by an equable climate and well distributed rainfall which enables her to derive a considerable portion of her wealth from grasslands. Nevertheless we have had to adopt farming methods to suit the environment so that the greatest benefits may be derived from the natural advantages with which New Zealand is endowed.

New Zealand has proceeded a long way since the early days of her farming when little was known of the environmental requirements of individual pasture species in order that they may produce to their maximum. It is unquestionable that much of the progress already made in grassland husbandry in this country is due to the wide range of trials conducted by the Department of Agriculture and Grasslands Division, D.S. and I.R., particularly over the last quarter of a century. Much has been learnt in the past and investigations being pursued at the present time will no doubt be reflected by improved methods of grassland husbandry with consequent increased pasture production in the future.

The original technique of pasture establishment was to sow a wide range of species in the hope that at least one specie would persist and form a sward. This idea changed as the farming community came to know the environmental conditions necessary for the persistence and production of the individual species. In this way seeds mixtures became simpler containing those species suited to the particular environment of the land being laid down to pasture. However, despite the sowing of the correct species there are numerous other factors warranting consideration before high pasture production can be obtained. Thus methods of pasture establishment and pasture management have been investigated and improvements have been effected through the application of the results obtained. Breeding work on the more important pasture species has been performed and resultant improved strains have been made available to the farmer per medium of the Seed Certification Scheme. Applications of artificial fertilizers have also played a major part in the improvement of New Zealand's pastures.

It is evident from the above that most research in New Zealand, directed towards maximum yields of high quality herbage, has considered only the aboveground parts of the pasture plants. However, it must be remembered that the aboveground parts of plants are dependent on the underground organs for the supplying of water, nutrients and the storage of reserves as well as acting as a mechanical support for the plant. Moreover, it has been demonstrated that there exists significant interrelationships between leaf production and underground development. When one considers that the main aim of grassland husbandry is to produce and maintain maximum production of high quality herbage this interrelationship thus indicates the great importance of the underground parts. Therefore an understanding of the functions of roots, their relationship to the aboveground organs and the response of plants to the various environmental factors affecting the roots is practically indispensable.

We all realize that a child has to be nursed if it is to survive and fit into place in this world. The same is true also of pastures. In the establishment period of a pasture it has to be nursed so that it will ultimately produce to a high level and in the case of permanent pastures, be persistent. In the past, and the same even applies today, poor pasture establishment has limited the production obtainable from pastures in a great number of instances. No matter how good the seed, a pasture will not be very successful if environmental conditions are not conducive to rapid and successful establishment.

It is known that, with members of the Gramineae family, the seminal roots are the first roots to develop and support the developing plant until such time as the nodal root system becomes functional. In view of this it is surprising that little work has been performed on the relationship between this seminal root system and pasture establishment. Further investigations on their importance in the early life of a pasture, their response to environmental conditions and the relative value of the various seminal roots and the nodal roots to the plant are thus worthy of pursuance.

In this experiment, by means of root amputations, an effort was made to evaluate the importance of the various seminal roots and the nodal roots to perennial ryegrass (Lolium perenne) in the presence and absence of superphosphate. The degree of tillering, herbage yields and the survival of plants were used as standards of judgment of the plants' response to the varying treatments.

SECTION II.

REVIEW OF LITERATURE.

When one reviews the literature it is soon seen that most attention has been focused on the aboveground parts. A lesser amount deals with the underground organs and there is a scarcity of material regarding the seminal roots of plants. Further, there is very little on the interrelationships between the above- and belowground organs even though they have been shown to be closely interrelated.

This state of affairs is no doubt due, to a large degree, to the great difficulties which one has to overcome when adequate observations are to be made on root development in order that reliable results can be obtained and correct interpretations of these results arrived at. Some of the more important difficulties that one is liable to come up against are:-

(1) Variation in plant material.

(2) Soil variations under natural environmental conditions.

(3) As a result of (1) and (2) large numbers of plants have to be observed.

(4) Tedious work involved in observations on root development.

(5) Lack of efficient yet speedy techniques.

Notwithstanding these difficulties, many workers have made observations on root development but there is still a large field available for detailed and pertinent research on underground development and importance of roots.

A. TERMINOLOGY.

It is at once obvious when the literature is perused that many synonyms are used to denote the different types of roots. To prevent any misunderstanding I shall enumerate these synonyms and also the terms that will be used throughout the remainder of this paper.

Jacques (1) discusses the types of roots of the nodal root system of perennial ryegrass. He lists them as follows:-

(1) Purely absorptive roots.

(2) Storage as well as absorptive roots.

(3) A type intermediate between the above.

He states, however, that the functioning and significance of these types is still a matter of conjecture and requires to be fully investigated.

However, members of the Gramineae family possess two distinct root systems and within these two there are distinct types of roots. When the seed germinates the seminal or primary root system develops and consists of one to several main roots and their branches. The primary seminal root develops first and in some cases is the only seminal root to develop. It is also known as temporary and primary root. In the majority of cases, however, more seminal roots develop after the appearance of the primary seminal root. These are known as lateral roots. Unfortunately the use of this term may lead to confusion in that brances of the nodal roots are referred to as lateral roots. Thus for the purposes of clarity the lateral roots of the seminal root system will be referred to as the lateral seminal roots. Figure 1 illustrates these various types of roots.

Later on in development, more especially when the plants begin to tiller, a root system begins to develop from the nodes at or near the soil surface. This root system is known as the secondary root system. Other terms given to these roots are crown roots, adventitious roots and nodal roots. Through the remainder of this paper I shall refer to them as nodal roots.

To summarise then a list is given below of the terms used and the synonyms met with in the literature on root systems.

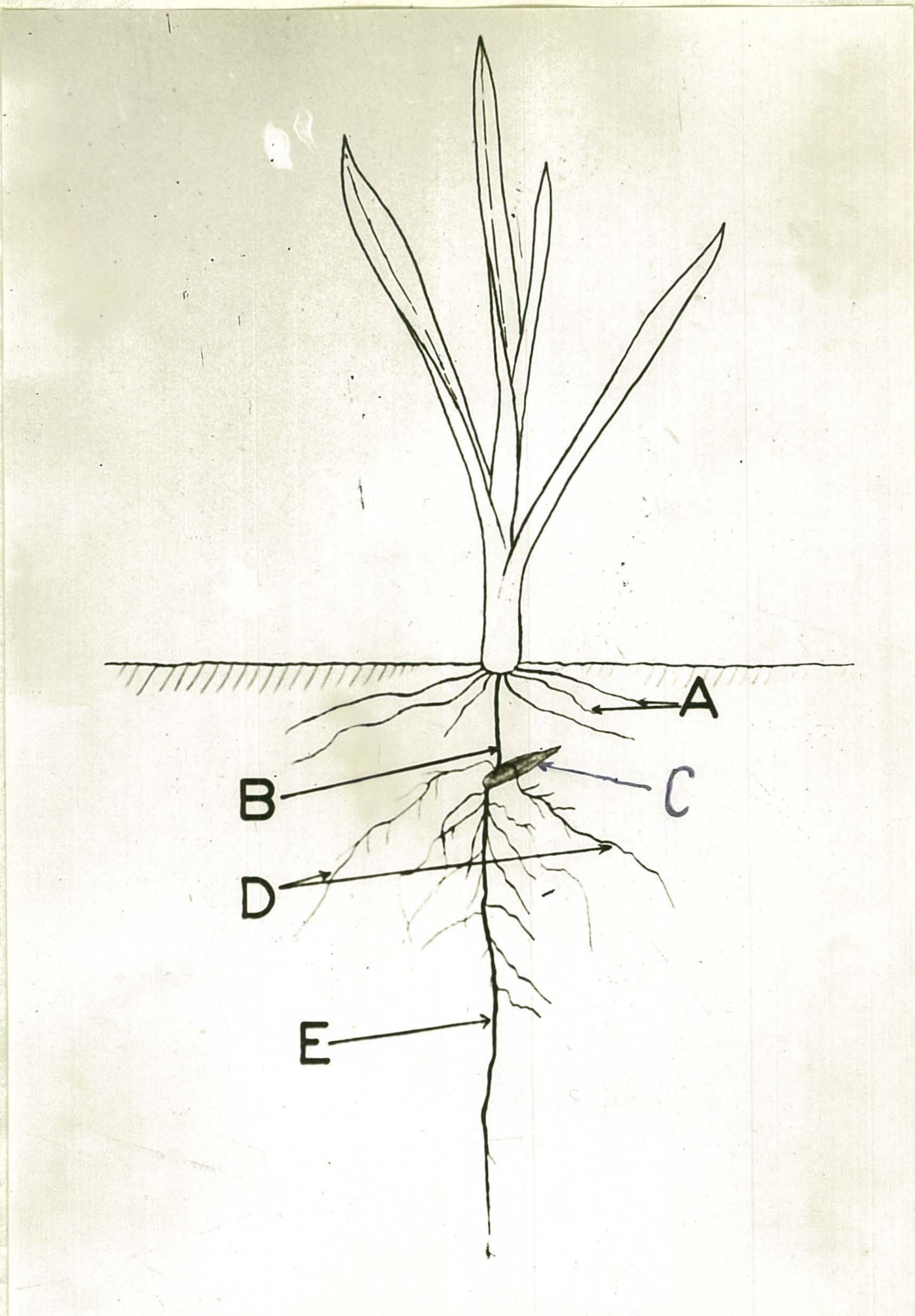

FIGURE I. Diagrammatic representation of the various roots of the gramineae family.

A. Nodal roots.

B. Internode.

C. Seed.

D. Lateral seminal roots.

E. Primary seminal root.

Term Used	Synonyms	
Nodal Roots	Crown, adventitious, secondary roots.	
Primary Seminal Roots	Temporary, Primary Root	Make up the Seminal or Primary Root System.
Lateral Seminal Roots	Lateral, Temporary and Primary Roots	

B. GENERAL DEVELOPMENT OF THE SEMINAL ROOTS.

Upon germination the embryonic plant previously dormant in the seed is released. Plants of the grass family possess two distinct root systems which develop at different periods. The seminal root system develops immediately upon germination and usually consists of several roots, the number of which depends on the species of plant.

According to Pavlychenko (2) the number of seminal roots varies within narrow limits and is apparently governed by a definite genetic factor. The following, extracted from results obtained by him, support his statement:-

Annual Grain Crops.

Crop	Number
Avena fatua (Wild oats)	3.0
Avena sativa (Cultivated oats)	3.1 - 3.5
Triticum aestivium (Wheat)	3.6 - 5.0
Secale cereale (Rye)	4.5 - 5.3
Hordeum distichon (Barley)	6.5 - 8.5

Perennial Grasses.

Specie	Agropyron cristatum			Agropyron pauciflorum			Bromus inermis		
Days after emergence	5	15	30	5	15	30	5	15	30
Av. No. of Seminal Roots per plant.	1.6	2.6	2.4	1.5	1.2	1.1	2.3	2.0	2.0

Further, it will be observed that the number of seminal roots was smaller in the perennial grasses studied than in the annual grain crops. However, it must be realised that the above figures apply only to the conditions under which the experiments were conducted. Environmental factors such as climate and soil conditions modify the average numbers of seminal roots but the variation within species is limited under the same conditions.

McCall (3) with respect to wheat states that "When the seed is exposed to moisture water is absorbed and the seed swells. At appropriate temperatures the embryo begins to push out both the coleorhiza and the coleoptile, the former somewhat more rapidly than the latter. The seed coat is ruptured, the coleoptile turns upward and the primary (seminal) root pierces the coleorhiza and turns downward. Shortly after the primary (seminal) root has pierced the coleorhiza the lower pair of lateral (seminal) roots emerge through the axis cortex, followed soon after by the second pair of lateral (seminal) roots just above the first pair."

The young seedling is entirely dependent on this seminal root system until later, during the period of tillering, the second root system, the nodal root system, develops from the lower nodes of the main stem and of the tillers. Once the nodal root system is established the seminal root system is no longer an absolute necessity, it finally dies and its place is taken over by the nodal root system.

To appreciate fully the significance of seminal roots for the survival of a plant one must recognise that during development prior to emergence the size of the plant increases about four times. This is supported by results obtained in a study by Pavlychenko (4). The seminal roots of various crop plants at emergence were of the following length:-

Specie	In Greenhouse	In Field
Marquis wheat	12.62 ins.	24 ins. approx.
Hannchen barley	14.75 "	27 " "
Banner oats	6.6 "	14 " "
Wild oats	6.95 "	13 " "

With respect to later development, Weaver and Zink (5) obtained the following figures working with various grasses. At 21 days after planting when the plants were 1½ to 5 inches high the seminal roots were 6 to 10 inches deep. Nodal roots and tillers were only just beginning to develop. At 41 days the grasses were about 8 to 10 inches tall and well tillered. At this stage the seminal roots reached a depth of 7½ to 27 inches and the nodal roots were often equally deep. At 90 to 123 days when the grasses were 9 to 19 inches tall, the seminal roots, despite a large number of nodal roots, extended deeply and frequently to 24 inches in depth. Microscopic examination showed about half to two-thirds of the seminal root system to be intact. (Based on the condition of the cortex).

These figures then serve to indicate the tremendous development of the seminal roots and how important they are to developing plants even until they reach an age of three months at which time the nodal root system is extensive and fully functional. It will also be realised that any serious damage to the seminal root system prior to the development of the nodal roots will cause the death of the plant. Further, damage caused to the seminal root system once the nodal roots have begun to develop may have serious effects on the development of the plant depending, however, on the stage to which the nodal roots have developed.

C. LENGTH OF LIFE OF SEMINAL ROOTS.

Since root study necessitates much more difficult technique due to their inaccessability, the length of life of the seminal roots, and also the nodal roots, remains a disputed question.

The seminal roots are often designated as temporary in general text books and even in special books on grasses of recent publication notwithstanding that experimental evidence has proved this conclusion to be incorrect. For example Robbins (6) states: "The primary roots, those that arise directly from the seed, are temporary, dying after the permanent roots are able to support the plants." More recently Nelson (7) states: "The function of the seminal root system is temporary and is to provide for the supply of the seedling stage only. Later on it dies." Hitchcock (8) states: "The primary root persists only a short time after germination, its place being taken by secondary roots (nodal roots) produced from the nodes of the young culm."

However, observations and experimental trials have shown that the seminal root system is by no means temporary in all cases. Members of the Gramineae family have been observed as reaching maturity while existing on only the seminal root system.

Locke and Clarke (9) observed that in two different instances where extremely dry surface soil, packing or crusting of the soil prevented normal development of the nodal roots, the seminal roots furnished sufficient moisture to maintain growth of wheat plants to maturity or until rain occurred and the permanent roots developed normally. Simmonds and Sallans (10) found through amputation studies that the wheat plant may produce seed when dependent almost entirely upon the seminal roots. Simmonds (11) at a later date stated that the seminal roots remain functional throughout the life of the plant. Krassovsky (12) working on the physiological activity of seminal roots demonstrated that the seminal roots of wheat, barley and rye were active up to the time of harvest. Results obtained by Pavlychenko (4) in studies over a period of nine years gives conclusive evidence that, in annual grasses in arid climates, seminal roots function throughout the entire growing season, and what is more important, they are frequently the only roots supporting the plant from emergence to maturity.

The above deal with annual species. ×Studies on the seminal roots of perennial grasses are very meagre.

Stoddart (13) in 1935 found that the seminal roots of *Andropogon furcatus* all lived to an age of 18 months and some were still functioning at the end of two years. This indicates then that the seminal roots may live in excess of two years. Rapport (14) reports that the tap root (primary seminal root) of *Lolium perenne* was discernable after three months and growth was still proceeding. Weaver and Zink (5) observed that the seminal roots of fourteen perennial grasses were usually deep and spread widely whilst they remained alive and active as absorbing organs for 3½ to 4 months.

From the above evidence then, one can conclude that where the climate and soil conditions are favourable for nodal root development the seminal roots die, once the former are capable of supporting the plant. This has apparently led to the conclusion that the seminal roots are temporary. However, where climate and soil conditions are unfavourable, or where artificially induced conditions have retarded nodal root development then the length of life of the seminal roots is increased.

To sum up then one may say that the seminal root system is normally short-lived but under adverse conditions it may persist for longer periods and may even allow the plant to reach maturity.

D. TILLERING AND ROOT DEVELOPMENT.

The interrelationships between the two root systems and tillering have not been thoroughly investigated. Results obtained on this aspect by various workers are usually mentioned more or less incidentally to the main theme of the various papers.

Olmsted (15) observed that plants with no nodal roots were retarded in growth as compared with plants bearing functional nodal roots. Glendinning (16) found that tillering was closely associated with the establishment of the nodal root system in *Heteropogon*. McCall (3) mentions that where the nodal roots fail to develop the wheat plant does not tiller to any extent even though the seminal root system is capable of carrying the plant to maturity. According to Weaver (17) the production of tillers is successful only when the nodal root system penetrates into the moist soil and meets the increased demand for water.

Krassovsky (12) determined that the seminal roots supply principally the main stem and the nodal roots the tillers. The removal of the seminal roots during the period of stalking depressed the development of the main stem and lengthened the period of vegetation whereas the removal of the nodal roots checked tillering and hastened maturity. One can, on the basis of Krassovsky's results, draw the conclusion that the seminal roots serve the main stem whilst the nodal roots supply the tillers.

It is evident then from the above that the removal of nodal roots or the failure of nodal roots to develop, has a definite effect on tillering, in that tiller production is suppressed.

E. <u>THE IMPORTANCE OF THE VARIOUS ROOTS.</u>

It is of importance here to consider the developmental anatomy of the Gramineae family in relation to the importance of the various roots. It has been already stated that the primary seminal root is the first root to appear followed by the first and second pair of lateral seminal roots. At a later date the nodal roots make an appearance and finally tend to take over the functions of the seminal roots.

McCall (3) states: "As the food supply from the endosperm is conveyed along the scutellum trace, its most direct route leads to the first node and into the coleoptile. The portion of the scutellum trace passing on the first node is much larger than the branches leading to the coleoptile. Thus it appears that the connection of this large trace to the node insures that the primary seminal root is well supplied with materials for growth." This is supported by the fact that most workers have observed the growth of the primary seminal root to be most rapid. McCall (3) showed this to be due to a most efficient conducting system which connects the first node to all the bundles of the root axis. The coleoptile, in wheat, is somewhat slower in growth even though it is connected directly to the food supply and is probably due to the fact that the coleoptile has only two bundles supplying it and depends on diffusion to a large extent.

The first pair of lateral seminal roots are also directly connected to the first nodal plate and as a result they are in a position to draw directly on the labile food supply. Consequently they emerge almost immediately after the primary seminal root and the growth of them is almost as rapid as that of the primary seminal root.

The second pair of lateral seminal roots frequently do not develop or if they do so they are much slower in growth and do not become as extensive as the primary and first pair of lateral seminal roots. In the case of wheat McCall (3) says that this is the result of the less favourable placement of them in relation to the food stored in the endosperm. To reach them the food must pass either from the first node or through the relatively smaller connections from the coleoptile bundles. In the former case they have to compete with the primary and first pair of lateral seminal roots and in the latter case with such structures as the coleoptile and the plumule. That the amount of food material available through these channels is not alwsys adequate is shown by the fact that in a large number of cases this pair does not develop or if it does develop their slower growth shows the result of their less favourable position.

From the above, some basis is thus given for the relative development and extent of the various seminal roots. As a result, the value of the various seminal roots to the plant varies according to their ability to develop quickly and extensively.

Sallans (18) found that the various roots of the wheat plant contribute independently of each other to the water and mineral supply of the plant as was indicated by the final yield of grain. His data given below illustrates that, of the seminal roots, the primary seminal root contributes most to the final yield. The first pair of lateral seminal roots are of approximately equal importance whilst the second pair of lateral seminal roots are of much less importance.

Amputation Treatments	Dry top weights 1938	Yield of grain 1939
None	4.135	2.075
Primary seminal root	3.555	1.605
1st pair lateral seminal roots	3.602	1.855
2nd pair lateral seminal roots	3.792	1.860
All seminal roots	1.535	1.220

Thus we see that the value of the seminal roots is closely linked with their development.

The contribution of the nodal roots to the wheat plants' yield of grain is much more variable than is the case with the individual seminal roots. Sallans (18) states: "At Saskatoon in 1939 the nodal roots individually were less valuable than the other classes taken singly. In the aggregate, however, they contributed 61% of the total yield. At Indian Head in 1938 they contributed 63.6% of the total yield." With respect to variability in 1929 at Indian Head the nodal roots produced 65.5% of the check yield whilst in 1930 they produced only 36% as much grain.

The importance of the seminal roots in the early stages of development was supported by further data of Simmonds and Sallans(10). In their work, amputations of seminal roots on 21st July resulted in no reduction of yield whereas amputations on June 9th caused a loss of 64% in yield as shown in the controls. At the latter date the nodal roots were just developing and were not in a position to take over the supplying of water and minerals to the plant. Hence the earlier in the developmental stage of the nodal roots that the seminal roots are amputated the more marked is the loss of these roots.

Krassovsky (12) found that in wheat, barley and rye that the seminal roots were more effective in water absorption, absorbing almost double the amount of water per unit of dry weight in comparison to the nodal roots. This further emphasises the importance of the seminal root system in annual grain crops.

With respect to perennial grasses very little is known about the importance of the various roots. Much contradictory evidence has been put forward concerning the persistency of the seminal roots and this has no doubt led to the belief that they are of no great importance to a plant once it has established. Work employing amputation studies would no doubt help to clarify the position.

F. CONCLUSIONS.

We have seen that the seminal roots are of great importance to annual grain crops often enabling them to reach maturity in the absence of nodal roots due to unfavourable conditions. However, reduction in yield and tillering results with the non-development of the nodal roots. Work by Simmonds and Sallans has illustrated the relative importance of the various roots to the wheat plant.

Work on perennial grasses is somewhat scarce but it has been shown that they are important at least until the nodal roots have developed.

SECTION III.

PRELIMINARY INVESTIGATIONS.

A. GENERAL DESCRIPTION.

A preliminary experiment to enable observations on the general development of the root systems of various species and varieties to be made, was laid down on the 31st March, 1949.

Observations on the root systems of the following were made:-

Perennial ryegrass	: *Lolium perenne*
Italian ryegrass	: *Lolium multiflorum*
Toowoomba grass	: *Phalaris tuberosa*
Creeping bent	: *Agrostis stolonifera var. compacta*
Dryland brown-top	: *Agrostis tenuis*
Brown-top	: *Agrostis tenuis*

The main observations were concerned with the extent and number of seminal roots, their diameter and the root hair development on both the seminal and nodal roots. Drawings of the root systems were made for all plants lifted. Lifting was carried out at approximately four day intervals.

B. EXPERIMENTAL METHOD.

The area on which the experiment was laid down was in paddock four, Massey Agricultural College Dairy Farm. The area was 50 feet by 30 feet in size, reasonably sheltered and level. The soil is described as a Manawatu sandy loam, being of high fertility but showing a pasture response to superphosphate and lime (19). The area had previously been a vegetable garden. This was ploughed in March, 1949 and worked down to a rubbly condition. Half the area was further worked down by hoeing and raking so that the seed for the general root observations could be sown on the 31st March, 1949. The remaining half of the area was left in fallow, being cultivated at intervals to keep germinating weeds in check.

No fertilizer was applied to plants of this preliminary investigation.

When seed of the Gramineae family is planted shallow or when it germinates in the light, both root systems are closely connected, the nodal roots surrounding the seminal roots so that the latter can scarcely be noticed. When the seed is planted deep, the nodal roots are obviously separated from the seminal roots by an elongated wiry internode. In this and the root amputation experiment, the seed was sown at a depth of ¾ inch so that the two root systems could be distinguished.

The seed of the different species or varieties was obtained from the Grasslands Division of the D.S. and I.R. Three seeds per plant position were sown, there being twelve plant positions per specie or variety. All plant positions were fifteen inches apart each way. The plants were not sown according to any experimental design which would enable statistical analysis of the results because it was realized that insufficient numbers of plants would be observed. Each specie or variety was confined to a single row and lifting of the plants began at one end of each row and subsequent liftings proceeded along the row in order.

Plants were lifted at intervals and observations on root development were made, particular emphasis being placed on the development of the seminal root system. The first lifting was carried out on the 12th April, 1949 and continued thereafter at approximately four day intervals until the 30th May, 1949.

The technique of lifting the plants and the separation of the roots was as follows. The soil was excavated from around each plant position so that a block of soil containing the required plant or plants was formed. The dimensions of the block were normally nine inches square and initially nine inches in depth, but this was increased for the last three observations to a depth of twelve inches. These were the dimensions observed for the ryegrass species; in the case of the remaining species a depth of six inches was sufficient for all liftings. From observations in the laboratory these appropriate depths were on the safe side, the roots penetrating only to a depth somewhat above the point of severance of the soil prisms.

When the blocks of soil had been exposed they were sliced off at their base with a large knife and then carefully placed in a tin tray.

The roots were then partially separated out in the field by washing with a gentle spray of water. The separation was not thorough at this stage, due to the use of improvised equipment and much soil and organic matter was left clinging to the roots. On completion of this partial separation the plants were placed on damp appropriately labelled filter paper and transferred to the laboratory.

In the laboratory root separation was completed by further careful washing, organic matter being removed with the aid of forceps, and the plants were then placed in suitably labelled bottles until observations on root development could be made.

This method of root separation proved to be satisfactory, most root systems being obtained entire. The method employed, however, did not give information on the distribution of the roots in the soil. Greater detailed study during separation from the soil would have yielded information on this point but, because of the number of plants to be lifted and the time required to make a more detailed investigation, the experimenter was limited to merely separating out the roots and making the laboratory observations.

For the laboratory observations the plants were placed in glass dishes containing water. The glass dishes containing the plants were then placed over graph paper and drawings to actual scale were made on further graph paper. The roots were arranged in the glass dishes in such a manner that the drawing of them was facilitated and not to give any indication of their distribution in the soil.

When the drawings were completed measurements on the following were made:-

(i) Length of the primary seminal root.

(ii) Greatest depth of a nodal root when lying naturally in water.

(iii) Height of the leaves when lying naturally in water.

(iv) Number of leaves.

(v) Number of seminal roots.

(vi) Number of nodal roots.

The roots were then studied in water under a binocular microscope to give information of the following:-

(i) Diameter of the various seminal roots one millimeter from the embryo.

(ii) Number of lateral roots on each seminal root.

(iii) Average diameter of the lateral roots of the various seminal roots.

(iv) The degree of branching.

(v) The condition of the cortex on the nodal roots, seminal roots and the lateral roots of the seminal roots.

(vi) Root hair development on the nodal roots, seminal roots and the lateral roots of the seminal roots.

C. <u>RESULTS.</u>

The number of plants lifted at each date varied according to the number present in each plant position. Three seeds had been sown in each plant position but all did not germinate so, when lifted, there were from one to three plants of each specie or variety available for study. Data in the tables then are averages of the plants observed at the respective lifting dates. This gave a more composite view of the development and condition of the root systems.

Note that in the tables and text, seminal root A denotes the primary seminal root and seminal roots B, C & D the various lateral seminal roots.

The individual species and varieties will be dealt with in turn followed by a general summary.

(i) <u>Perennial Ryegrass : Lolium perenne</u>

The plants emerged ten days after sowing and the first lifting took place three days later on the 12th April, 1949. Thereafter the plants were lifted every four days (except the second lifting which was six days after the first lifting) until the 16th May, 1949, whilst the last two liftings were at

TABLE I. RESULTS OF OBSERVATIONS ON PERENNIAL RYE GRASS ROOT SYSTEM IN THE EARLY STAGES OF PLANT DEVELOPMENT.

Lifting Date	12.4.49	18.4.49	22.4.49	26.4.49	30.4.49	4.5.49	8.5.49	12.5.49	16.5.49	23.5.49	30.5.49
Days after Sowing	13	19	23	27	31	35	39	43	47	54	61
Days after Emergence	3	9	13	17	21	25	29	33	37	44	51
Number of Plants Studied	3	2	2	1	2	3	3	3	2	3	2
Number of Leaves	1	2	2	2	4	4	4.3	6.3	7.5	5.3	13.5
Number of Nodal Roots	1.6	2.5	3.5	5	7	8.3	7.3	7.6	9	8	9
Number of Seminal Roots	3.3	3	2	3	3.5	2.3	2.6	2.3	2.5	2.6	3
Height in inches	1.73	2.47	2.52	2.37	2.55	2.93	2.43	3.29	1.87	2.34	3.04
Length of longest Seminal Root in inches	1.34	2.43	2.51	2.52	3.02	4.01	3.05	3.98	4.88	4.20	7.37
Greatest Depth of Roots in inches	1.96	2.97	3.11	3.21	3.42	4.47	3.36	4.32	5.29	4.96	7.78
Diameter of Seminal Root A in M.M.	.037	.029	.029	.031	.030	.029	.024	.028	.027	.026	.030
" " " " B " M.M.	NM	NM	.018	.015	.017	.015	.014	.015	.019	.016	.019
" " " " C " M.M.	NM	NM	—	.014	.018	.020	.015	.016	.018	.016	.015
" " " " D " M.M.	NM	NM	—	.020	.018	—	—	.018	—	.014	—
Order of Branching of Seminal Root System	1st	1st	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd	3rd
Number of Lateral Roots on Sem. A.	8	29.5	36.5	21	26	56.6	34	51.3	52	34	26.5
" " " " " " B.	0	0	7.5	2	15	10	4.3	13	54	16	20.5
" " " " " " C.	0	0	—	0	8	17	1.5	3	3	2.5	13
" " " " " " D.	0	0	—	7	19	—	—	21	—	2	—
Total Number of Laterals on the Sem. R.S.	8	29.5	44	30	68	83.6	39.8	88.3	109	54.5	60
Diameter of lateral roots of Sem. A in M.M.	.012	.012	.015	.016	.014	.014	.014	.015	.015	.013	.014
" " " " " " B "	Nil	Nil	NM	.014	.010	.011	.011	.013	.014	.010	.013
" " " " " " C "	Nil	Nil	—	Nil	NM	.012	.010	.011	.0135	.011	.011
" " " " " " D "	Nil	Nil	—	.014	NM	—	—	.014	—	.010	—
Root hair development nodal roots	Nil	A	A	A	A	A	A	A	A	A	A
" " " seminal roots	A	A	A	A	A	A	G	G	G	G	F
" " " lateral roots	A	A	A	G	A	A	G	A	G	A	A
Condition of cortex nodal roots	I	I	I	I	I	I	I	I	I	I	I
" " " seminal roots	I	I	I	I	I	I	I	I	I	I	Sb
" " " lateral roots	I	I	I	I	I	I	I	I	I	I	I

weekly intervals the last being on the 30th May, 1949.

The measurements and results of observations are shown in Table I.

Over the observation period there was a steady increase in the number of leaves there being an average of 13.5 leaves at the final lifting, 61 days after sowing. The height of the leaves did not increase uniformly with age there being a variation from 1.73-3.29 inches over the whole period. Thus development of leafage was reflected in increased number rather than in increased height attained by the plants.

The seminal root system increased in length fairly uniformly reaching an average maximum length at the final observation of 7.37 inches. At no stage had the nodal roots penetrated as deeply as the seminal root system. The discrepancy between the length of longest seminal root and the greatest depth of roots is due to the wiry internode between the base of the plant and the embryo of the seed.

The number of seminal roots also showed a variation ranging from one to five in number. The number of plants with the various numbers of seminal roots is shown in Table II.

<u>TABLE II.</u> The number of Perennial Ryegrass plants with varying numbers of seminal roots:

Number of Seminal Roots	Number of Plants	Total Number of Seminal Roots
1	2	2
2	10	20
3	7	21
4	6	24
5	1	5
Totals	26	72
Mean number of Seminal Roots		2.77

From this table we see that two seminal roots was the most frequent number; it being presumed that where only two seminal roots are developed that the primary seminal root and one root of the first pair of lateral seminal roots have developed.

The mean number of seminal roots developed, however, was 2.77. This is due to the fact that an almost equal number of plants produced three and four seminal roots. From Table I it will be seen that there was no tendency for the number of seminal roots developed to increase or decrease over the period of the observations. It appears then, that the requisite number of seminal roots are developed early in the plant's life and does not increase; or decrease, until the nodal roots have developed.

With respect to the diameter of the seminal roots there was very little change over the period of observation. The diameter of the primary seminal root was relatively constant, being about 0.030 M.M. (See Sem. A in Table I), but it is to be noted that it was greater in diameter than the lateral seminal roots. The lateral seminal roots had a diameter approximating 0.016 M.M. and at each observation date the various lateral seminal roots were of similar diameter.

There was a gradual change in the extent of branching of the seminal root system, having attained the 3rd order by the 30th May, 1949. However, with this change there was not a consistent increase in the number of lateral roots (1st order branches) with increasing age of the plants. The total number did increase with age, but varied greatly from one lifting date to the next. Also, the number of lateral roots on the various seminal roots varied so that it was not possible to come to any accurate conclusion. It is to be remembered that soil conditions have an influence on root development, and, since there were insufficient numbers of plants observed, the numbers varied from one lifting date to the next. However, it will be seen from Table I that the primary seminal root tended to develop more lateral roots than did the lateral seminal roots.

The diameter of these lateral roots were fairly constant from one observation date to the others. It will be noticed that the lateral roots of the primary seminal root were greater in diameter (approximately 0.014 M.M.) than the lateral roots of the lateral seminal roots, the latter being fairly constant for each lateral seminal root at about 0.011 M.M.

in diameter.

Root hairs were abundant on the seminal roots until the 4th May, 1949 after which there occurred a general decline until the final observation. The root hairs were most abundant near the root tips of both the seminal roots and the lateral roots. So far as the lateral roots are concerned, root hairs were abundant over almost the whole period of observation, there being a slight decline towards the end of the period. Root hairs were abundant on the nodal roots at all observations except the first when these roots were only just making their appearance.

The cortex was intact on the nodal and lateral roots at all observations. The cortex of the primary seminal root and lateral seminal roots was observed as being intact until the 23rd May, 1949. At the final lifting the cortex of these roots was beginning to slough. At the same time root hair development was described as being only fair (see Table I).

It seems then that the nodal roots were taking over the supplying of nutrients and water to the plants at this last observation.

To summarise then, with perennial ryegrass the seminal root system remained active up to 61 days after sowing but at the end of the period the nodal roots were extensive and the seminal roots were sloughing their cortex. Of the various seminal roots the primary seminal root was the most extensive, the lateral seminal roots being somewhat smaller and less developed, but, with plants having two or more lateral seminal roots, there was little difference in size and development between the lateral seminal roots.

(ii) <u>Italian Ryegrass</u> : <u>Lolium multiflorum</u>

The plants were lifted on the same dates as perennial ryegrass except that none were lifted on the 16th May, 1949. The plants emerged nine days after sowing and were first lifted four days after emergence. The measurements and results of observations at the various dates are shown in Table III.

TABLE III. RESULTS OF OBSERVATIONS ON ITALIAN RYEGRASS ROOT SYSTEM IN THE EARLY STAGES OF PLANT DEVELOPMENT.

Lifting Date	12.4.49	18.4.49	22.4.49	26.4.49	30.4.49	4.5.49	8.5.49	12.5.49	16.5.49	30.5.49
Days after sowing	13	19	23	27	31	35	39	43	47	61
Days after emergence	4	10	14	18	22	26	30	34	38	52
Number of Plants Studied	3	2	3	3	2	1	1	3	2	3
Number of Leaves	1	2	2	2.6	4	5	7	5.6	7.5	8
Number of Nodal Roots	1	3.5	3.6	4.6	4.5	6	8	6.6	9	7.3
Number of Seminal Roots	2	2	2.3	2.6	2.5	2	2	2.3	3	3
Height in inches	1.41	2.01	2.10	2.06	2.37	2.13	1.5	1.82	3.68	3.26
Length of longest Seminal Root in inches	1.54	2.16	2.82	4.15	5.18	2.9	7.76	2.71	5.21	4.85
Greatest Depth of Roots in inches	2.21	3.11	3.41	4.64	5.74	4.23	8.46	3.55	5.96	5.26
Diameter of Seminal Root A in M.M.	.036	.029	.030	.027	.026	.029	.031	.028	.029	.022
" " " " B " M.M.	NM	NM	.021	.013	.012	.016	.016	.015	.017	.014
" " " " C " M.M.	NM	NM	.018	.012	.016	—	—	.016	.020	.011
" " " " D " M.M.	—	—	—	.012	—	—	—	.018	.014	—
Order of Branching of Seminal Root System	1st	1st	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd
Number of Lateral Roots on Sem. A.	13.66	24	25.66	29.33	49.5	26	69	12	44	27
" " " " " " B.	0	0	5.5	7	1	18	4	1.3	12.5	49
" " " " " " C.	0	0	4.5	0	0	—	—	0	46	1
" " " " " " D.	—	—	—	0	—	—	—	0	7	—
Total Number of Laterals on the Sem. R.S.	13.66	24	35.66	36.33	50.5	44	73	13.3	109.5	77
Diameter of lateral roots of Sem. Root A in M.M.	0.015	0.014	.014	.011	.012	.014	.014	.013	.013	.014
" " " " " " " B " "	Nil	Nil	.011	.009	T.S.	.010	.011	.010	.010	.013
" " " " " " " C " "	Nil	Nil	.011	Nil	Nil	—	—	Nil	.012	.011
" " " " " " " D " "	—	—	—	Nil	—	—	—	Nil	.011	—
Root hair development nodal roots	Nil	A	A	A	A	A	A	A	A	A
" " " seminal roots	A	A	A	G	G	G	G	F	G	Nil
" " " lateral roots	A	A	A	G	A	A	G	G	G	P
Condition of cortex nodal roots	I	I	I	I	I	I	I	I	I	I
" " " seminal roots	I	I	I	I	I	I	I	Sb	Sb	S
" " " lateral roots	I	I	I	I	I	I	I	I	I	Sb

ABBREVIATIONS:-

NM = Not measured I = Intact

Height in inches	1.41	2.01	2.10	2.06	2.37	2.13	1.5	1.82	3.68	3.26
Length of longest Seminal Root in inches	1.54	2.16	2.82	4.15	5.18	2.9	7.76	2.71	5.21	4.85
Greatest Depth of Roots in inches	2.21	3.11	3.41	4.64	5.74	4.23	8.46	3.55	5.96	5.26
Diameter of Seminal Root A in M.M.	.036	.029	.030	.027	.026	.029	.031	.028	.029	.022
" " " " B " M.M.	NM	NM	.021	.013	.012	.016	.016	.015	.017	.014
" " " " C " M.M.	NM	NM	.018	.012	.016	—	—	.016	.020	.011
" " " " D " M.M.	—	—	—	.012	—	—	—	.018	.014	—
Order of Branching of Seminal Root System	1st	1st	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd
Number of Lateral Roots on Sem. A.	13.66	24	25.66	29.33	49.5	26	69	12	44	27
" " " " " " B.	0	0	5.5	7	1	18	4	1.3	12.5	49
" " " " " " C.	0	0	4.5	0	0	—	—	0	46	1
" " " " " " D.	—	—	—	0	—	—	—	0	7	—
Total Number of Laterals on the Sem. R.S.	13.66	24	35.66	36.33	50.5	44	73	13.3	109.5	77
Diameter of lateral roots of Sem. Root A in M.M.	0.015	0.014	.014	.011	.012	.014	.014	.013	.013	.014
" " " " " " " B " "	Nil	Nil	.011	.009	T.S.	.010	.011	.010	.010	.013
" " " " " " " C " "	Nil	Nil	.011	Nil	Nil	—	—	Nil	.012	.011
" " " " " " " D " "	—	—	—	Nil	—	—	—	Nil	.011	—
Root hair development nodal roots	Nil	A	A	A	A	A	A	A	A	A
" " " seminal roots	A	A	A	G	G	G	G	F	G	Nil
" " " lateral roots	A	A	A	G	A	A	G	G	G	P
Condition of cortex nodal roots	I	I	I	I	I	I	I	I	I	I
" " " seminal roots	I	I	I	I	I	I	I	Sb	Sb	S
" " " lateral roots	I	I	I	I	I	I	I	I	I	Sb

ABBREVIATIONS :-

NM = Not measured — I = Intact

A = Abundant — Sb= Beginning to slough

G = Good — S = Sloughed

F = Fair — T.S.= Too small for measurement

P = Poor

* Measurements, on 30. 5.49, on the seminal root system was limited to one plant only. The seminal root system of the other two plants had sloughed off and decayed.

These results show that there was a steady increase in the number of leaves, reaching an average of eight leaves at the final observation 52 days after emergence. As with perennial ryegrass there was not a uniform increase in height, but it did tend to increase with age reaching an average of 3.26 inches on the 30th May, 1949.

The seminal roots reached an average length of 4.85 inches on the 30th May, 1949 but the increase in length with age was not uniform. For example on 8th May, 1949 one plant was lifted and its longest seminal root was 7.76 inches whereas three plants lifted on the 12th May, 1949 had an average length of 2.71 inches.

The number of seminal roots varied from one to four as shown in Table IV.

TABLE IV. The number of Italian Ryegrass plants with varying numbers of seminal roots.

Number of Seminal Roots	Number of Plants	Total Number of Seminal Roots
1	3	3
2	9	18
3	7	21
4	2	8
Totals	21	50
Mean Number of Seminal Roots		2.38

From this table we see that approximately equal numbers of plants developed two or three seminal roots indicating that the primary seminal root and either one or both of the first pair of lateral seminal roots developed in the majority of the plants. There was no tendency for the number of seminal roots to increase over the period of observation, varying at different dates from two to three. The mean number of seminal roots was 2.38 being lower than was the case with perennial ryegrass.

The diameter of the primary seminal root remained fairly constant over the period of study approximating 0.030 M.M. which is similar to that of perennial ryegrass (0.030 M.M.). The lateral seminal roots, as with perennial ryegrass, were smaller in diameter than the primary seminal root, approximating 0.016 M.M. The various lateral seminal roots of the one plant were of approximately the same diameter.

With this specie at the last observation the plants had branches of the second order, unlike that of perennial ryegrass which at the same date had attained the third order of branching. There was not a consistent increase in the number of lateral roots after the 30th April, 1949 although there appears to be a tendency towards increased numbers. In general the primary seminal root had more lateral roots than the lateral seminal roots, commonly developing over half the total number of lateral roots.

The diameter of these lateral roots remained fairly constant at about 0.014 M.M. on the primary seminal root and these lateral roots were slightly greater in diameter than were the lateral roots of the lateral seminal roots.

Root hairs were abundant on the seminal roots until 23 days after sowing after which there was a general decline until the cortex was sloughed off. Of the plants lifted on the 30th May, 1949 one plant had sloughed off its cortex whilst with the two remaining plants the seminal root system had died. The lateral roots of the seminal roots showed abundant root hair development until the fifth week after sowing after which there was a decline to the final observation nine weeks after sowing. Root hairs were abundant on the nodal roots at all observations except the first, when the nodal roots were just beginning to develop.

The cortex remained intact on the nodal roots at all observations. The cortex was sloughed off the seminal roots after the 8th May, 1949 but remained intact on their lateral roots until the last observation when some sloughing of the cortex was noted.

In conclusion then the nodal roots appeared to have taken over the functions of the seminal roots by the time of the last observation on the 30th May, 1949, 61 days after sowing. Also, as with perennial ryegrass, the primary seminal root was the most developed seminal root.

(iii) Toowoomba grass : *Phalaris tuberosa*

The plants were lifted at four day intervals between the 22nd April, 1949 and the 16th May, 1949. This specie was much slower than the ryegrasses in establishing, emerging nineteen days after sowing. The measurements and results of the observations are shown in Table V.

TABLE V. RESULTS OF OBSERVATIONS ON PHALARIS TUBEROSA ROOT SYSTEM IN THE EARLY STAGES OF PLANT DEVELOPMENT.

Lifting Date	22.4.49	26.4.49	30.4.49	4.5.49	8.5.49	12.5.49	16.5.49
Days after Sowing	23	27	31	35	39	43	47
Days after Emergence	4	8	12	16	20	24	28
Number of Plants Studied	2	2	1	1	1	1	2
Number of Leaves	1.5	1.5	2	2	2	1	3
Number of Nodal roots	3	3	2	4	3	4	4
Number of Seminal roots	1	1	2	3	1	2	1.5
Height in inches	.85	1.11	2.47	2.22	1.92	1.86	2.06
Length of longest seminal root in inches	.77	1.02	1.78	5.45	1.16	2.5	3.13
Greatest depth of roots in inches	1.09	1.44		5.85	1.78	3.1	3.88
Diameter of Seminal Root A in M.M.	.016	.020	.033	.029	.025	.029	.031
" " " " B " M.M.	—	—	.016	.016	—	.022	.022
" " " " C " M.M.	—	—	—	.018	—	—	—
Order of Branching of Seminal Root System	1st	1st	1st	1st	1st	1st	2nd
Number of Lateral Roots on Seminal R. A.	4	8.5	8	20	6	5	12
" " " " " " " B.	—	—	0	0	—	0	2
" " " " " " " C.	—	—	—	0	—	—	—
Total Number of Laterals on the Sem. R.S.	4	8.5	8	20	6	5	14
Diameter of Laterals of Sem. A in M.M.	.012	.012	.017	.020	.018	.024	.021
" " " " " B " M.M.	—	—	Nil	Nil	—	—	NM
" " " " " C " M.M.	—	—	—	Nil	—	—	—
Root Hair Development nodal roots	F	A	A	A	A	A	A
" " " seminal roots	A	A	F	A	A	A	A
" " " lateral roots	A	A	G	A	A	F	A
Condition of Cortex nodal roots	I	I	I	I	I	I	I
" " " seminal roots	I	I	I	I	I	I	I
" " " lateral roots	I	I	I	I	I	I	I

ABBREVIATIONS:-

NM = Not Measured

A = Abundant

G = Good

F = Fair

I = Intact.

The number of leaves did not increase greatly over the period only reaching an average of three 47 days after sowing. It reached an average height of 2.06 inches by the final observation (47 days after sowing). This then illustrates the slow establishing nature of this specie.

The seminal roots did not reach a great length, reaching an average of 3.13 inches at the last observation. The increase in length was gradual, except for one plant which was lifted on the 4th May, 1949 and its seminal root system was 5.45 inches long 35 days after sowing.

The number of seminal roots varied between one and three as shown in Table VI.

TABLE VI. The number of *Phalaris tuberosa* plants with varying numbers of seminal roots.

Number of Seminal Roots	Number of Plants	Total Number of Seminal Roots
1	6	6
2	3	6
3	1	3
Totals	10	15
Mean Number of Seminal Roots		1.5

The mean number of seminal roots developed was 1.5. This is a much lower mean number than is the case with either perennial or Italian Ryegrasses. Due to the small number of plants observed it is difficult to state whether there is an increase or not, with increasing age, in the number of seminal roots. It appears that there is no increase.

The diameter of the primary seminal roots increased up to the third lifting on the 30th April, 1949 and thereafter approximated 0.029 M.M. The lateral seminal roots when present were smaller in diameter than the primary seminal root(C.F. Perennial and Italian Ryegrasses.)

This specie had branches of the first order until the final lifting when second order branches were observed to be developing. The total numbers of lateral roots were not high at any lifting but it is to be noted that the primary seminal root had developed more lateral roots than the lateral seminal roots. The diameter of these branches increased up to the fourth lifting and remained fairly constant thereafter at about 0.02 M.M. No lateral roots of the lateral seminal roots were measured when present, so, as to whether they are smaller, or not, than those of the primary seminal roots remains unknown.

Root hair development was variable possibly due to the fact that the plants were still establishing. However, at the last observation root hairs were abundant on all roots.

The cortex was intact on all plants lifted and studied.

To summarise, it is evident that Phalaris tuberosa is slow to establish when compared with the two ryegrasses and this is reflected in less well-developed leaf and root systems at comparable dates after sowing. However, as with the two ryegrasses this specie develops its primary seminal root to a greater degree than its lateral seminal roots.

(iv) Brown-top : Agrostis tenuis.

This specie did not establish rapidly emerging sixteen days after sowing. It did not grow to any extent as is indicated by the number of leaves, height and extent of the root system. From the first observation, seven days after emergence, to the final observation thirty-one days after emergence there was very little increase in the size of the plants. The results of measurements and observations are shown in Table VII.

TABLE VII. RESULTS OF OBSERVATIONS ON BROWN-TOP ROOT SYSTEM IN THE EARLY STAGES OF PLANT DEVELOPMENT.

Lifting Date	22.4.49	26.4.49	4.5.49	8.5.49	12.5.49	16.5.49
Days after Sowing	23	27	35	39	43	47
Days after Emergence	7	11	19	23	27	31
Number of Plants Studied	1	2	1	1	3	1
Number of Leaves	2	1.5	2	3	1.6	3
Number of Nodal Roots	4	3.5	2	6	4	3
Number of Seminal Roots	1	1	1	2	1.3	1
Height in inches	0.9	1.0	0.75	0.75	0.76	0.35
Length of longest Seminal Root in inches	1.84	0.58	0.78	0.94	0.67	0.78
Greatest Depth of Roots in inches	1.96	1.06	1.40	1.50	1.14	1.08
Diameter of Seminal Root A in M.M.	.022	.017	.018	.018	.016	.016
" " " " B " M.M.	—	—	—	.011	.011	—
Order of Branching of Seminal Root System	1st	1st	1st	1st	1st	
Number of Lateral Roots on Seminal Root A.	15	6	11	9	6.3	0
" " " " " " " B.	—	—	—	0	0	—
Total Number of Lateral Roots on the Sem. R.S.	15	6	11	9	6.3	0
Diameter of Lateral Roots of Sem. Root A in M.M.	.011	.010	.010	.009	.010	Nil
" " " " " " " B " M.M.	—	—	—	Nil	Nil	—
Root Hair Development of Nodal Roots	A	G	P	G	F	G
" " " " Seminal Roots	A	G	P	G	F	G
" " " " Lateral Roots	A	G	P	G	F	
Condition of Cortex Nodal Roots	I	I	I	I	I	I
" " " Seminal Roots	I	I	I	I	I	I
" " " Lateral Roots	I	I	I	I	I	

ABBREVIATIONS:-

A = Abundant

G = Good

P = Poor

F = Fair

I = Intact

In Table VIII are given the number of plants with varying numbers of seminal roots.

TABLE VIII. The number of Brown-top plants with varying numbers of seminal roots.

Number of Seminal Roots	Number of Plants	Total Number of Seminal Roots
1	7	7
2	2	4
Totals	9	11
Mean Number of Seminal Roots		1.22

It is to be noted that the number of seminal roots developed was either one or two and that the mean number was 1.22 per plant. This is lower than the mean numbers of the two ryegrass species and Phalaris tuberosa. From Table VII as with the other species we see that the primary seminal root was developed to a greater extent than the lateral seminal roots, when present, in both diameter and number of lateral roots.

Root hair development varied from one lifting date to the next but in general was not good on any of the various roots. The cortex was intact at all observations on the various roots.

(v) Creeping bent : Agrostis stolonifera var. compacta.

As was the case with Brown-top this specie did not grow to any great extent over the observation period. It was as slow as brown-top in establishing, emerging seventeen days after sowing. Results obtained at the various liftings are shown in Table IX.

TABLE IX. RESULTS OF OBSERVATIONS ON CREEPING-BENT ROOT SYSTEM IN THE EARLY STAGES OF PLANT DEVELOPMENT.

Lifting Date	22.4.49	26.4.49	30.4.49	4.5.49	8.5.49	12.5.49	16.5.49	23.5.49	30.5.49
Days after Sowing	23	27	31	35	39	43	47	54	61
Days after Emergence	6	10	14	18	22	26	30	37	44
Number of Plants Studied	1	1	2	2	2	1	1	1	1
Number of Leaves	2	1	1.5	2	2.5	2	4	3	5
Number of Nodal Roots	4	3	1.5	6.5	6	5	3	10	5
Number of Seminal Roots	3	1	1	1.5	1	2	1	1	1
Height in inches	1.3	0.75	0.63	0.76	0.93	0.73	0.28	0.63	0.47
Length of longest Seminal Root in inches	1.15	0.62	0.68	0.90	0.98	0.50	1.16	0.84	1.71
Greatest Depth of Roots in inches	1.45	1.13	1.12	1.41	1.48	1.30	1.30	1.92	1.98
Diameter of Seminal Root A in M.M.	.016	.014	.015	.016	.016	.011	.014	.011	.018
" " " " B " M.M.	.012	—	—	.009	—	.009	—	—	—
" " " " C " M.M.	.010	—	—	—	—	—	—	—	—
Order of Branching of Seminal Root System	1st	1st	1st	1st	1st	1st		1st	1st
Number of Lateral Roots on Seminal Root A.	11	5	3.5	8.5	6.5	1	0	6	1
" " " " " " " B.	0	—	—	0	—	0	—	—	—
" " " " " " " C.	0	—	—	—	—	—	—	—	—
Total Number of Lateral Roots on the Sem. R.S.	11	5	3.5	8.5	6.5	1	0	6	1
Diameter of Lateral roots of Sem. Root A In M.M.	.010	.017	.008	.011	.007	.010	Nil	.007	.011
" " " " " " " B " M.M.	Nil	—	—	Nil	—	Nil	—	—	—
" " " " " " " C " M.M.	Nil	—	—	—	—	—	—	—	—
Root Hair Development of Nodal Roots	P	G	P	A	A	A	A	A	A
" " " " Seminal Roots	F	G	P	G	P	P	F	F	A
" " " " Lateral Roots	A	G	G	A	P	P		A	
Condition of Cortex Nodal Roots	I	I	I	I	I	I	I	I	I
" " " Seminal Roots	I	I	I	I	Sb	I	Sb	Sb	I
" " " Lateral Roots	I	I	I	I	I	I		I	

ABBREVIATIONS:-

P = Poor   I = Intact

F = Fair   Sb = Beginning to slough.

G = Good

A = Abundant

Of the various roots the primary seminal root was developed to a greater degree than either the nodal or lateral seminal roots at all observations. It was greater in diameter than the lateral seminal root and was the only seminal root to develop lateral roots. The mean number of seminal roots was 1.33 with a range of one to three. (See Table X).

TABLE X. The number of Creeping-bent plants with varying numbers of seminal roots.

Number of Seminal Roots	Number of Plants	Total Number of Seminal Roots
1	9	9
2	2	4
3	1	3
Totals	12	16
Mean Number of Seminal Roots		1.33

The cortex remained intact over the period on both the nodal and lateral roots but showed evidence of sloughing off the seminal roots over the last few observations. Root hair development was variable but showed a tendency to decline with age on the seminal roots.

(vi) Dryland Brown-top : *Agrostis tenuis*.

As with the other *Agrostis* species dryland brown-top established slowly and growth was practically nil after emergence. Results of observations and measurements are given in Table XI.

TABLE XI. RESULTS OF OBSERVATIONS ON DRYLAND BROWN-TOP ROOT SYSTEM IN THE EARLY STAGES OF PLANT DEVELOPMENT.

Lifting Date	22.4.49	26.4.49	30.4.49	8.5.49	12.5.49	16.5.49	23.5.49	30.5.49
Days after Sowing	23	27	31	39	43	47	54	61
Days after Emergence	6	10	14	22	26	30	37	44
Number of Plants Studied	1	1	2	1	1	1	1	1
Number of Leaves	2	2	2	2	2	4	3	3
Number of Nodal Roots	5	4	3.5	5	4	4	10	8
Number of Seminal Roots	1	2	1.5	2	1	1	1	1
Height in inches	1.16	0.7	0.67	0.85	0.65	0.44	0.87	0.60
Length of longest Seminal Root in inches	0.86	0.77	0.66	0.98	0.83	0.95	1.36	1.01
Greatest Depth of Roots in inches	1.20	1.07	1.33	1.68	1.05	1.15	1.54	1.32
Diameter of Seminal Root A in M.M.	.018	.018	.014	.018	.027	.011	.016	.016
" " " " B " M.M.	—	NM	.010	.011	—	—	—	—
Order of Branching of Seminal Root System	1st	1st	1st	1st	1st		1st	
Number of Lateral Roots on Seminal Root A.	5	9	2	11	7	0	17	0
" " " " " " " B.	---	0	0	0	---	---	---	---
Total Number of Lateral Roots on the Sem. R.S.	5	9	2	11	7	0	17	0
Diameter of Lateral Roots of Sem. Root A in M.M.	.010	.012	.009	.009	0.13	Nil	.008	Nil
" " " " " " " B " M.M.	—	Nil	Nil	Nil	—	—	—	—
Root Hair Development of Nodal Roots	A	A	G	A	F	A	A	A
" " " " Seminal Roots	A	A	G	G	G	A	P	Nil
" " " " Lateral Roots	A	A	G	A	G		G	
Condition of Cortex Nodal Roots	I	I	I	I	I	I	I	I
" " " Seminal Roots	I	I	I	I	I	I	S	Sd
" " " Lateral Roots	I	I	I	I	I		I	

ABBREVIATIONS:-

A = Abundant I = Intact

G = Good S = Sloughing

F = Fair Sd = Sloughed.

P = Poor

Here again the primary seminal root was developed more than the lateral seminal roots having a greater diameter and more lateral roots. The mean number of seminal roots was 1.33, there being either one or two seminal roots developed (See Table XII).

TABLE XII. The number of Dryland brown-top plants with varying numbers of seminal roots.

Number of Seminal Roots	Number of Plants	Total Number of Seminal Roots
1	6	6
2	3	6
Totals	9	12
Mean number of Seminal Roots.		1.33

Root hair development also varied being poorest on the seminal roots at the final observation. The cortex remained intact over the observation period on the nodal and lateral roots but was sloughed off the seminal roots at the final observation.

D. SUMMARY.

The two ryegrass species established rapidly and developed the most extensive root system whilst the Agrostis species were slow to establish and did not make very much growth after emergence. Phalaris tuberosa was slower in establishing than the ryegrasses but after emergence growth of this specie was steady.

Of the various seminal roots the primary seminal root made the most extensive growth with all species. It had a greater diameter and developed a larger number of lateral roots than the lateral seminal roots. The average diameter of the lateral roots of the lateral seminal roots was less than that of the lateral roots of the primary seminal root. The nodal roots steadily grew and increased in number with increasing age and, with the ryegrass species at the final observations, was taking over the supplying of nutrients and water to the plants.

The number of seminal roots was confined to narrow limits with the *Agrostis* species and *Phalaris tuberosa* but varied more with the ryegrass species. The mean number of seminal roots was highest with the ryegrass species, decreasing to about 1.33 with the *Agrostis* species, whilst *Phalaris tuberosa* was intermediate. The mean number of seminal roots appears to be closely connected with the rate of establishment. Nothing definite on this aspect can be stated and further work on this point is required to enable a correct interpretation to be made.

Root hair development was observed to be closely connected with the condition of the cortex. Poor root hair development was associated with a poor condition of the cortex. With increasing age the cortex of the seminal roots began to slough off. and root hairs became less abundant. The nodal roots and lateral roots showed, in the main, no sloughing of the cortex and good root hair development over the whole observation period.

In Appendix VII photographs of drawings of the root systems of representative plants of perennial ryegrass, italian ryegrass and *Phalaris tuberosa* at the various lifting dates are presented.

SECTION IV.

OBJECT OF THE ROOT AMPUTATION EXPERIMENT.

It had been observed in the preliminary investigation that the primary seminal root was developed to a greater extent than the lateral seminal roots. This had also been pointed out by Sallans(18) with his work on wheat. He also determined the importance of the various roots to the wheat plant by means of root amputations.

In order to obtain knowledge on the value of the roots, particularly the seminal roots, to grass species a root amputation experiment was designed. Since perennial ryegrass (Lolium perenne) is New Zealand's main grass specie in pastures on high fertility soils it was decided to use this specie in the root amputation experiment. The experiment was designed so as to permit statistical evaluation of the results.

It was decided to measure the effect of the various treatments by means of tiller numbers, dry weight yields of herbage and, in the case of some treatments, by the death rate of plants undergoing those treatments. In this way it was believed that some information on the value of the various roots to perennial ryegrass could be obtained.

SECTION V.

EXPERIMENTAL METHOD.

A. GENERAL DESCRIPTION.

The experiment covered an observation and measurement period of five months. It consisted of various root amputation treatments and fertilizer application on perennial ryegrass (*Lolium perenne*).

The following were the root amputation treatments:-

Control or no roots amputated.

Primary seminal root amputated.

Lateral seminal roots amputated.

Primary and lateral seminal roots amputated.

Primary seminal and nodal roots amputated.

Nodal roots amputated.

Nodal and lateral seminal roots amputated.

Fertilizer treatments were two in number consisting of either the presence or absence of superphosphate. Each fertilizer treatment was applied to the set of root amputation treatments. This gave fourteen treatments in all. Thus seven plants were receiving different root treatments while another seven plants were receiving the same seven different root treatments as well as the fertilizer application.

Dry weight yields of herbage and tiller numbers were to be taken as indicating the response of plants to the various treatments.

B. THE EXPERIMENTAL AREA AND ITS PREPARATION.

The same area that was used for the preliminary investigations (See Page 16) was also used for this experiment. Lifting of the various plants in the preliminary investigation was completed by the end of May, 1949.

The whole area was then kept free of weeds by periodic cultivation until it was dug by hand during the third week of Septmber, 1949, approximately three weeks before sowing the seed. After digging it was immediately hoed and raked in order to give a fairly fine surface and promote consolidation. It received a further hoeing one week before sowing. Just prior to the application of the fertilizer the land was again hoed and raked. The seed-bed had by now worked down to a fine, firm condition and, at the same time, germinating weed seeds had suffered a check.

C. EXPERIMENTAL LAYOUT.

In this experiment statistical analysis of results was desired and accordingly the experimental layout was designed so as to permit efficient statistical analysis.

As mentioned under the sub-section 'General Description' (Page 39) there were to be seven root treatments and two fertilizer treatments applied to all the root treatments making fourteen treatments in all.

With any population, measurements on various features such as height, yield, growth etc., vary about a mean. The smaller the sample from this population the more chance there is of getting a sample mean varying widely from the population mean. By increasing the sample size the better an estimate we get of the population mean.

If, for example, two treatments were applied to two groups of plants, there being only a few plants in each group, the difference between the means of the groups is very much more likely to be distorted by random environmental factors or by individual peculiarities of the plants than if say 100 plants had been used in each group. Consequently the estimate obtained in an experiment of the difference in effect of the two treatments when applied to the whole population would be likely to be much less accurate with the smaller number of plants.

However, 100 replications of each treatment would mean increased work with possibly little gain in information over that obtained with a smaller number of plants. If 100 replications were made of the above mentioned root and fertilizer treatments 1,400 plants would have to be treated, observed and measured. This would be beyond the experimenter's capacity.

Edmond (20) found that somewhere in the region of 500 plants could be handled, but this figure depends on the complexity of the treatments and information required. With the fourteen treatments of this experiment approximately 36 replications would be possible on the basis of Edmond's work.

No information on variation between plants grown from seed, but treated alike, or of the differences between means likely to result from the treatments, was available so the use of the formula (21)

$$n = 2t^2 s^2 / \bar{x}^2$$

where t = 'Students' t for N-1 degrees of freedom.
s = Standard deviation
$\bar{x}$ = Difference between the means of the two groups

could not be used to estimate the number of plants required.

Edmond working with clonal plant material used fifteen replications. It was believed that his plant material was more uniform than is the case with plants grown from seed, as in this experiment. Moreover his work was conducted over a yearly period whereas this experiment was limited to five months duration and it was thus to be expected that differences between means would be somewhat smaller than occurred in Edmond's experiment, but this was by no means definite. The area available also limited the number of plants. It was decided then, in view of the above limitations, to adopt a figure of 32 replications.

Because of the uneven number of root treatments necessitating long narrow blocks, and because the blocks would be individually small, it was suggested by P. Armstrong (Biometrics Section D.S and I.R.) that a split-block designed experiment with double replication within blocks be used. Further, the split-block design would lessen the chance of non-fertilized plants deriving benefit from a possible lateral fertilizer movement in the soil or through the roots of non-fertilized plants growing into a fertilized soil zone.

In this way the fertilized plants were to be confined to one half of the whole-block and the non-fertilized plants to the other half. Because of the simple nature of the fertilizer treatments (presence or absence of superphosphate), it was considered desirable to apply the treatments at random to the sub-blocks rather than adopt a balanced arrangement of the fertilizer treatments. That both the fertilizer treatments occurred in the one whole-block was the only proviso. In this way it was hoped to allow for variation due to soil fertility gradient, soil heterogeneity etc.

The root treatments also were allotted at random. The sub-blocks were composed of two rows each of seven plants. Now all root treatments were to occur at random in each row. Hence the same root treatment did not occur more than once in the same row. There were four rows in each whole block, each root treatment occurring in each row once only. Fertilizer treatments were superimposed over two adjoining rows giving a split-block designed experiment. The arrangement of the experiment is shown in Figure 2 and indicates the treatment of each plant.

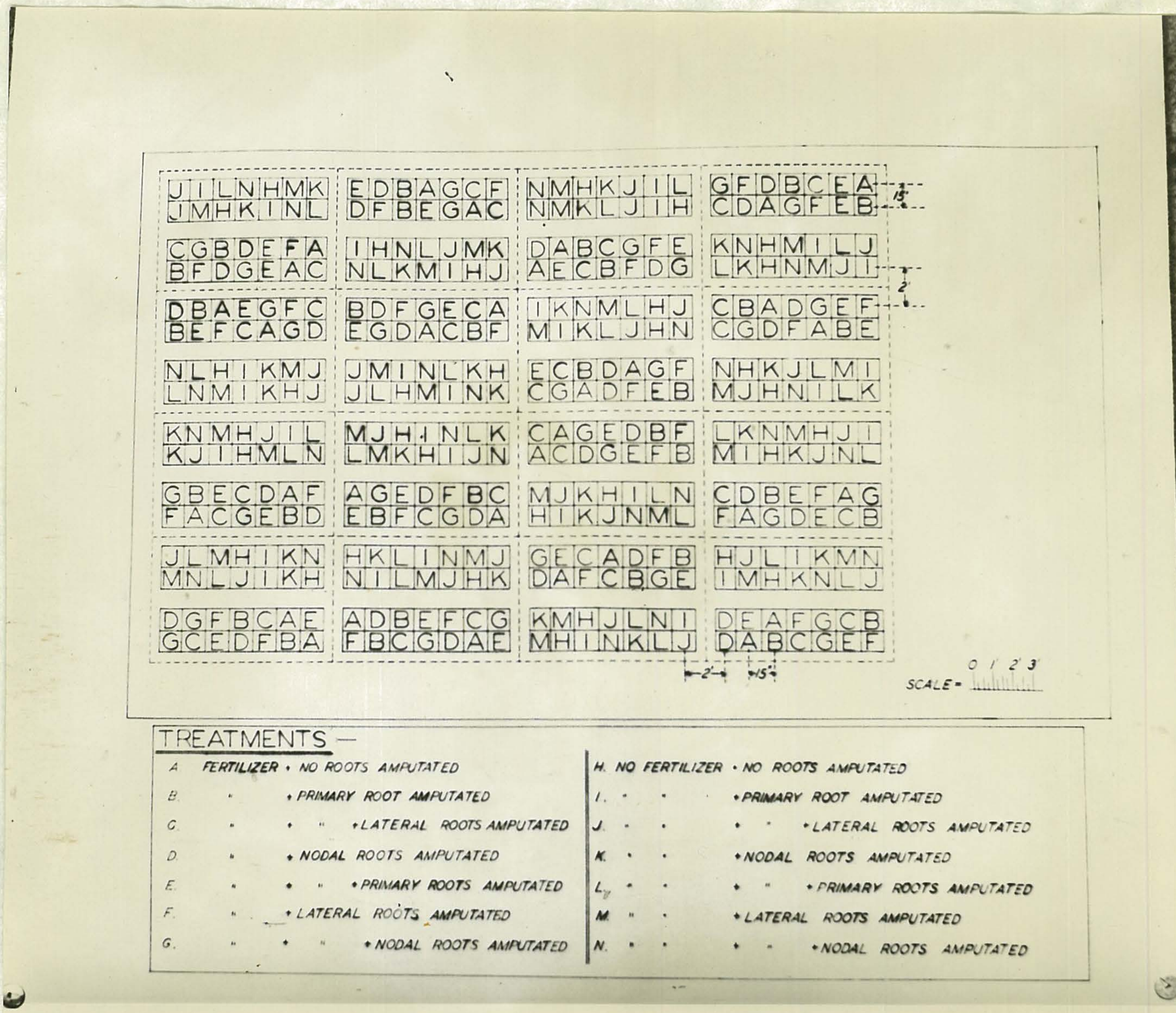

FIGURE 2. Experimental layout illustrating the randomisation of the root treatments within blocks and sub-blocks.

The plants were placed 15 inches apart within rows and 15 inches between rows within sub-blocks. The plants were numbered 1-7 along the first row and 8-14 along the second row. The sub-blocks were numbered 1-32 and were separated from each other by two feet. (Sub-blocks 1 and 2 equals one whole block, 3 and 4 equals the next whole block etc.) Blocks were also separated from each other by two feet. The ground around the area was kept cultivated and clear of weeds to prevent competition and border effect.

D. <u>FERTILIZER APPLICATION.</u>

In this root amputation experiment, as already mentioned, half of the plants in each block were to receive fertilizer. The fertilizer was applied to one half of each block i.e. each sub-block was either fertilized or non-fertilized.

These fertilized sub-blocks received an application of superphosphate at the rate of 5 cwt. per acre. 224 lots weighing 1.16 grammes of superphosphate, each equivalent to 5 cwt. per acre over the area of a circle six inches in diameter, were weighed out in the laboratory, put into paper envelopes and then taken to the experimental area.

The area was marked out by means of pegs and twine. Pegs marked the ends of the rows and columns. Twine was stretched between these pegs so as to give the correct intervals between plants, blocks and sub-blocks (1' 3" between plants, 2' between blocks and sub-blocks). Plant positions were indicated where the twine crossed. The use of twine and pegs in this manner to indicate plant positions not only facilitated the application of the fertilizer and sowing of the seed but also the observations which were carried out during the early stages of growth. Moreover, it ensured that the correct spacing of the plants, sub-blocks and blocks were obtained. Those sub-blocks which were to receive fertilizer were marked by labelled pegs before the fertilizer was applied.

The top inch of soil was removed from the plant positions that were to receive this fertilizer dressing. A plug of soil six inches in diameter and three inches in depth was then removed. This plug was placed in a tin tray and thoroughly mixed with the 1.16 grammes of fertilizer. After a thorough mixing the soil plus fertilizer was replaced and covered with an inch of soil to which no fertilizer had been applied. (See Figure 3).

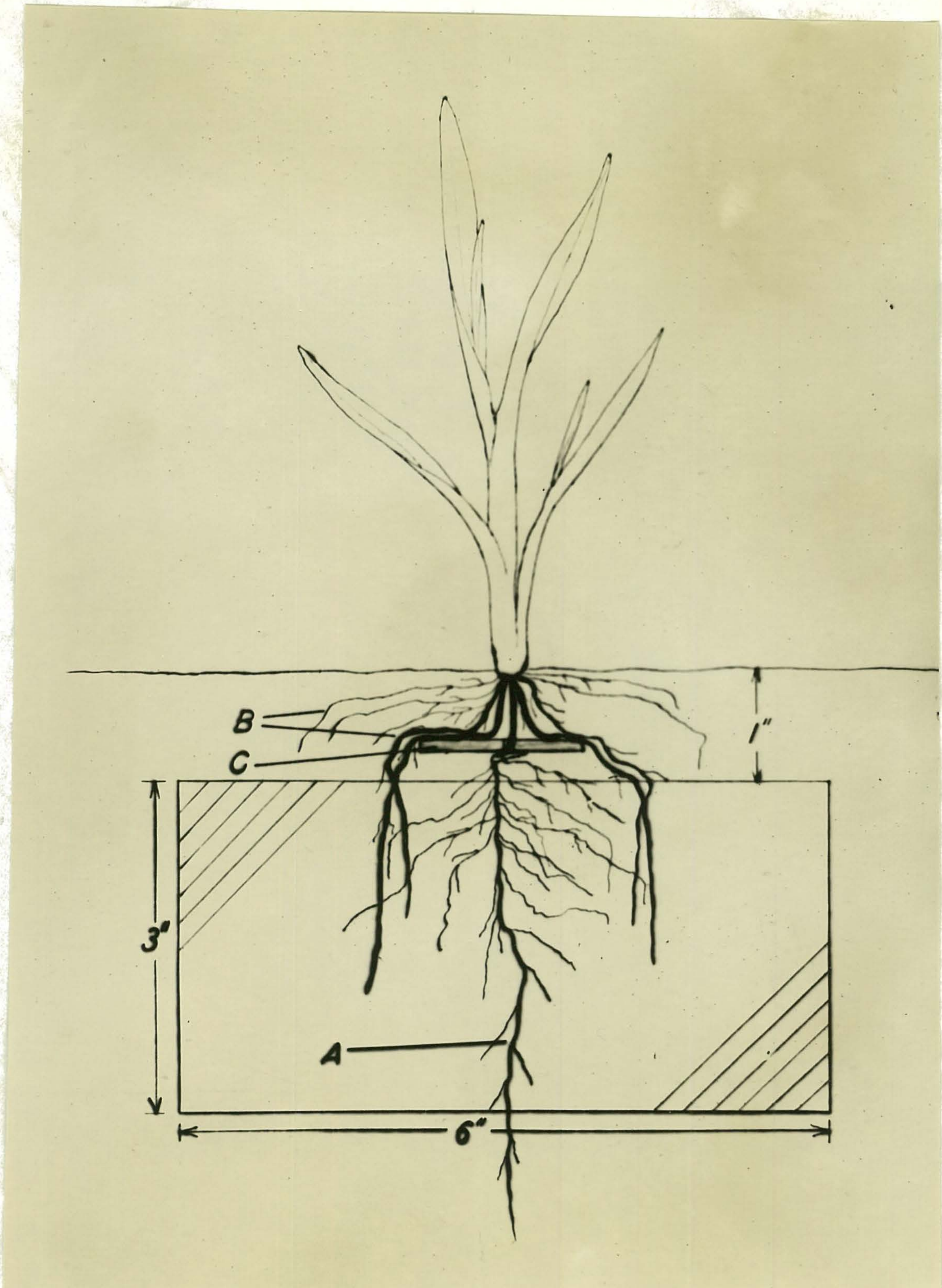

FIGURE 3. Diagrammatic representation of the placement of fertilizer in relation to the various roots. The fertilized soil zone is partially shaded.

A. Primary seminal root.

B. Nodal roots.

C. Rubber disc.

The fertilizer was placed in the above manner so that both root systems should come into contact with the fertilized soil. In the case of surface application the seminal root system would not come into contact with the fertilizer because, with the seed sown at ¾" depth, the seminal roots would have developed below the fertilized zone and because little movement of phosphate occurs in the soil. The method employed then would not place the seminal root system at a disadvantage. In fact the opposite would be more likely to occur with respect to rapidity of response since, the nodal roots would require a period of time to penetrate into the fertilized zone. However, considering the rapid growth of the nodal roots it was thought that the time lag would not be of importance, particularly since all plants were treated similarly and the amputation of the seminal roots did not take place until the nodal roots had penetrated into the fertilized zone.

In addition this method of application would have no depressing effect on the seed germination.

This method of fertilizer application was time consuming and had, of necessity, to be spread over two days, the 17th and 18th October, 1949.

E. THE SEED, ITS SOWING AND GERMINATION.

As already mentioned in Section XII Page 17, the seed was sown at a depth of ¾" so that the two root systems could be distinguished. In this root amputation experiment the seed was also sown at a depth of ¾" to enable not only the above but also to permit the rubber rings to be applied (See Page 49) to keep the two root systems separate.

For this experiment Perennial Ryegrass (*Lolium perenne*) seed was obtained from the Grasslands Division of the D.S. and I.R. This seed was harvested in 1948 from a single plant, A 246/327, which had been in nucleus isolation in a glasshouse. The seed, A 1695, from this single plant was described as being of good type and could qualify for certification as nucleus seed. This line of seed was considered, next to seed the result of a known cross, to give the most uniform results.

No seed of a known cross was available. However, from early observations, the seed appeared to germinate evenly, and growth was reasonably uniform.

The seed was sown on the 19th October, 1949 in a small hole ¾ inch deep. Three seeds per plant position were sown so as to lessen the chance of misses occurring. The positions of sowing were indicated in the same manner as were the positions for fertilizer application.

Two counts were made to give an indication of germination and to enable a determination of the effect of fertilizer on germination to be made. No effect was to be expected since the seed was sown above the zone of fertilizer. Percentages germination eight and eleven days after sowing were 77.5 and 86.3 respectively. With respect to the effect of fertilizer on germination, the results shown in Table XIII prove that no detrimental effect had occurred eleven days after sowing.

TABLE XIII. The total germination and the effect of fertilizer on germination eleven days after sowing.

	Fertilized	Non-Fertilized	Total
Number sown	672	672	1344
Number germinated	584	576	1160
Percentage germination	86.91	85.71	86.31

F. ROUTINE CARE OF THE PLOTS.

This consisted of frequent hand weeding in order to keep weed competition to a minimum and less frequent cultivation to overcome compaction or crusting of the soil.

Dock (*Rumex obtusifolius*), fat hen (*Chenopodium album*), red shank (*Polygonum persicaria*) and twin cress (*Coronopus didymus*) were the most troublesome weeds. Annual meadow grass (*Poa annua*) was the only pasture specie to make abundant appearance although a small amount of brown-top (*Agrostis tenuis*) did appear. No clovers were observed. The weeds and volunteer grasses were not difficult to control and as they appeared they were immediately checked.

Cultivation by hoeing not only kept the soil in a friable condition but at the same time effected a measure of weed control. Frequent trampling by the experimenter, in order to carry out the observations and treatments resulted in the compaction of the soil and cultivation was deemed to be advisable.

Hand weeding was done at weekly intervals whilst cultivation was carried out at approximately three weekly intervals.

G. <u>ROOT TREATMENTS.</u>

This consisted of the application of rubber discs and the amputation of various roots.

In this experiment with those treatments where the nodal roots were to be amputated, the two root systems had to be readily distinguished. Moreover, the base of the plant had to be exposed regularly to enable the nodal roots to be identified and their amputation effected. Accordingly a method adapted from that used by Weaver and Zink (5) was employed.

In place of a flat cork broken into halves and used in the manner described by Weaver and Zink, flat rubber discs $1\frac{1}{2}$ inches in diameter, $\frac{1}{8}$ inch in thickness with a small hole 1/16th inch in diameter in the centre were used.

These rubber discs were applied in order to the plants on the 8th to 10th November, 1949, 13-15 days after emergence when the plants had reached the two leaf stage. The soil at the base of the plant was excavated so that the seed was exposed. The leaves were then inserted into the small central hole and the rubber disc then slipped down the plant until it was lying just above the seed. The final position of the rubber disc is shown in figure 4.

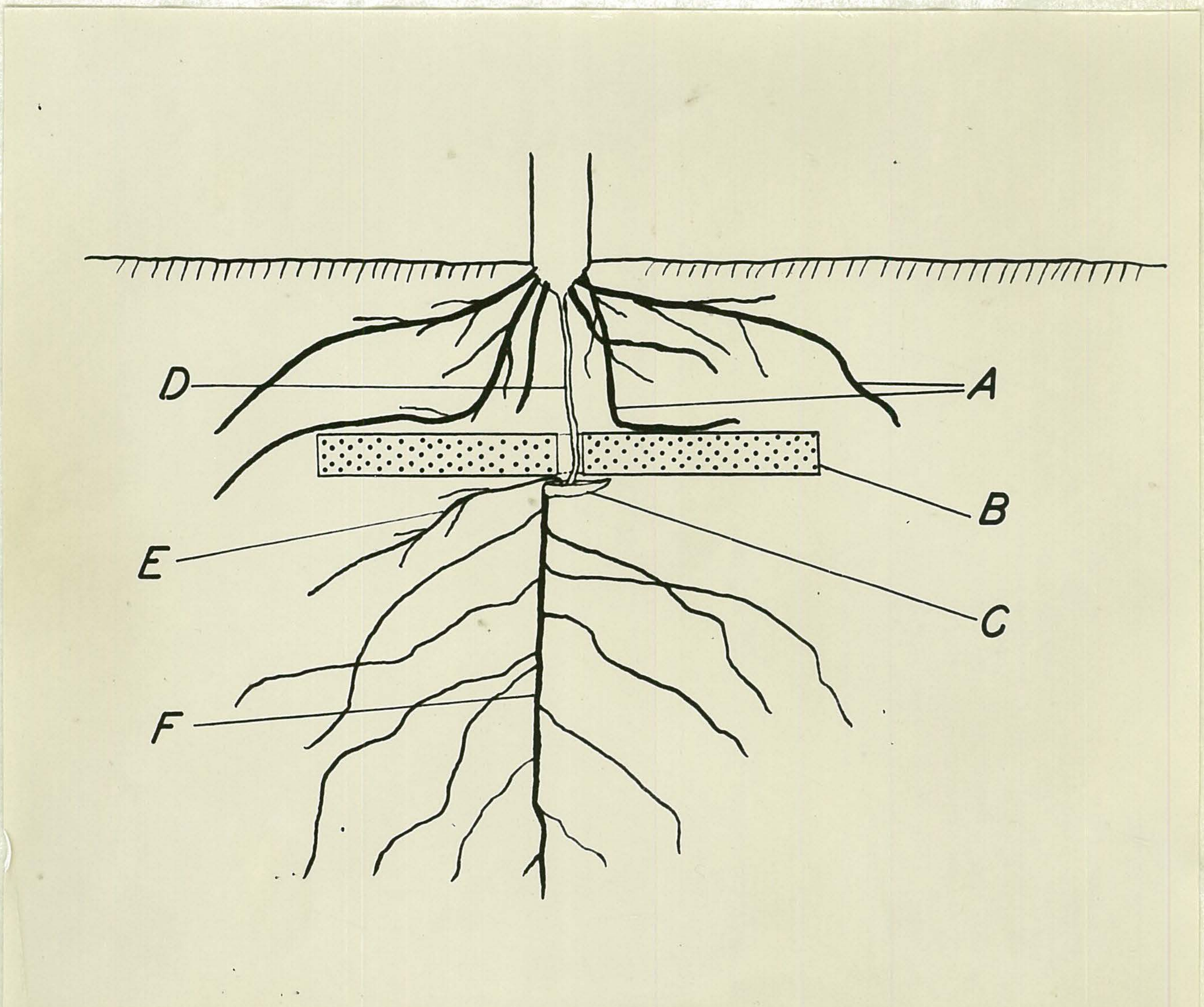

FIGURE 4. Diagram illustrating the position of the rubber discs in relation to the various roots.

A. Nodal roots.

B. Rubber Disc.

C. Seed.

D. Internode.

E. Lateral seminal root.

F. Primary seminal root.

In this way the wiry internode between the seed and the base of the plant was positioned through this central hole. Careful handling was necessary during the application of the discs in order that the internode was not broken or damaged. This did occur in a few cases and other developing plants, which were sown in the same plant position, were treated in the above manner. As a result, an undamaged plant was prepared to undergo the various root treatments. Two days after the application of the rubber discs, when it was definite that plants to which they were applied were not affected, the surplus plants in each plant position were removed.

The 448 plants of the experiment were treated in the above way so that this method was applied uniformly to all plants to ensure that no one root treatment would be affected favourably, or adversely, by the presence of the rubber discs.

When the nodal roots were to be amputated the soil was removed from around the base of the plant until the rubber disc was uncovered. It is to be noted that the rubber discs also kept the soil at the base of the plant somewhat dry and made for easier excavation of the soil. Whether or not this had any effect on root initiation was not determined. Edmond (20) observed that when the soil moisture falls to the 10-12% level root initiation appears to fail and above 25% it proceeds at a rapid rate. However, if the dryness of the soil was to inhibit root initiation then those treatments where the nodal roots were amputated would not be adversely affected, since minimum initiation of nodal roots is required from the point of view of their supplying nutrients and water to the plant and also their amputation. However, it must be kept in mind that the seminal roots are situated in a moister soil zone and may overcome to some extent this effect. In the treatments where the nodal roots are not amputated this effect would be further lessened because the nodal roots would also penetrate into a moister soil zone. When the soil had been removed, the wiry internode was identified and all roots produced from the base of the plant were cut back hard against the base of the plant with a small pair of scissors. The soil was then replaced.

The nodal roots rarely exceeded half an inch in length at each amputation. If they did, they normally came into contact with the rubber disc and grew along its surface. Consequently no disturbance of the seminal root system was necessary when the nodal roots were removed. Occasionally the nodal roots penetrated through the central hole but were easily distinguished from the internode between the seminal roots and the base of the plant. The latter was smooth, thin and lustreless whereas the nodal roots were whitish, translucent, thick and soil clung to the root hairs present on these roots.

The amputation of the nodal roots commenced on the 15th November, 1949 and from that date the amputations were carried out at approximately ten day intervals.

The amputation of the various seminal roots occupied two days. The seminal roots of the primary seminal root, nodal and primary seminal root and all seminal roots amputation treatments were amputated on the 22nd November, 1949, whilst the seminal roots of the lateral seminal roots and nodal and lateral seminal roots amputation treatments were amputated on the 23rd November, 1949. The technique employed was to excavate the soil and expose the upper portions of the seminal root, and the seed so that the various seminal roots could be identified. The primary seminal root was easily identified being thicker, penetrated vertically down into the soil and arose from the distal end of the seed. (Figure 1.)

The lateral seminal roots were more slender, penetrated at an angle to the verical plane into the soil and appeared from between the palea and lemma of the seed. The various seminal roots were amputated with a scalpel hard up against the seed.

In the treatment where all seminal roots were amputated the soil was not excavated to expose the seed etc., but only sufficiently to enable the wiry internode to be identified and severed.

The various seminal roots were amputated only once since they do not regenerate themselves. After amputating the various roots the soil was replaced and the plants were then ready for observations on the effect of these various root treatments.

With regard to the above technique, careful excavation and handling of the plants was required. Difficulties were experienced and, due to harsh treatment during excavation, some plants were damaged and did not survive. It was unfortunate that the surplus plants at the plant positions were disposed of after the application of the rubber discs and before the amputation of roots. In the results then, calculations to overcome the missing plant data had to be made.

H. TILLER COUNTING.

At various intervals the number of tillers were counted for each plant in all the treatments.

Tiller counting was relatively easy to do when the plants were in the early stages of development but became increasingly difficult with increasing age of the plants. Accordingly the last tiller count was made four days after the final cutting of the plants for herbage yield data. Upon cutting, the youngest leaf of each tiller grew rapidly and allowed for easier identification and counting of the tillers. Nevertheless, a check was made to ensure that each rapidly growing leaf arose from a tiller.

The number of tillers was recorded on data sheets in the field by sub-block number and plant number within the sub-blocks. These tiller numbers were later transferred to further data sheets under their appropriate treatment headings. (See

Appendices II-V).

Tiller counting was carried out on the following dates:-

2nd December, 1949.

16th December, 1949.

4th January, 1950.

15th March, 1950.

I. MEASUREMENT OF YIELD.

Sallans (18), working with wheat, showed that the amputation of the various seminal roots affected dry weight and grain yields. It was obvious soon after the commencement of this experiment that the various root treatments were affecting the herbage yields of the plants. Furthermore, with grassland experiments in New Zealand, most treatment effects are measured in terms of dry matter yields.

At the time of measuring dry matter yield in this experiment, the fertilizer treatments had effected statistically non-significant differences in tillering. It was anticipated that the dry matter determinations would give significant fertilizer treatment differences as well as significant root treatment differences.

Accordingly, the herbage was cut and weighed on 27-28th January, 1950 and 11th March, 1950. Only four root treatments were measured at both yield determinations. Nodal and primary seminal roots amputation treatment had no surviving plants at either of the cutting dates. Nodal roots amputation and nodal and lateral seminal roots amputation treatments had a few surviving plants at the first cutting date but these were considered to have insufficient growth for measurement. At the final cutting date there were no surviving plants of these two treatments.

The herbage was cut with modified sheep shears as adapted by Marryatt and Simpson (22). All the leaves of each plant were gathered together in one hand and then clipped with the shears. This ensured that the herbage was cut evenly to approximately two inches as well as helping to prevent it from falling off the shears. The clipped herbage was then placed in appropriately labelled paper bags. Labelling was effected by means of sub-block number and plant position number within the sub-blocks.

Dry weight was used as a basis of measurement of the herbage yield because of its greater accuracy and because it enables one set of results to be compared with another set of results (23).

The paper bags containing the herbage were then placed in a forced draught oven at the Grasslands Division, D.S. and I.R. where they were left to dry overnight at 75°C. This preliminary drying brought about a cessation of respiration as well as a reduction in the moisture content of the herbage. The following morning the samples were removed from the oven and drying completed in an unventilated Hearson oven for 8 hours at 100°-105°C. Since the Hearson oven was of limited capacity final drying of all the samples was proceeded with over a period of several days, but this was considered to be of no great importance because the preliminary drying had brought cell activity to a minimum.

When the drying was completed the samples were placed in one of two dessicators, one 12 inches in diameter and the other 8 inches in diameter. Fresh concentrated sulphuric acid was used as a drying agent in the dessicators.

When the samples had cooled down to the room temperature they were weighed on a Christian Becker Chainomatic balance to the nearest centigramme. As soon as the samples had been weighed, the paper bags were emptied of dried herbage and themselves weighed. The difference between these two weighings thus gave the dry matter yield for the appropriate plant. The Chainomatic balance enabled weighings to be completed rapidly. Because the paper bags and dried herbage were very hygroscopic and quickly took up moisture from the air, it was not considered satisfactory to weigh to more than the nearest centigramme. However, in this experiment accurate differences between treatments rather than accurate total yields were required and so it was considered that the method of weighing, that has been outlined, would be satisfactory.

J. COMPILATION OF RESULTS.

Survivals of plants, tiller numbers and dry weight yields of herbage were set out as shown in Appendices I-VI. From these appendices the data was grouped in various ways so that the differences, if any, could be observed.

During the course of the experiment plants in those treatments where the nodal roots were amputated died. It was obvious that the treatments caused their death and accordingly they were given zero tiller numbers. However, in those treatments where no nodal roots were amputated some plants also died and, because no reason could be seen why the treatments caused their death, a missing yield formula was used to give the statistically expected value.

The formula proposed by Yates (24) for evaluating missing plot data is as follows:-

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

where t = Number of treatments.

b = Number of blocks.

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

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

S = Sum of all observed items.

This formula had to be modified because of the split-block designed experiment and double replication of the treatments within the blocks. The modified formula used is as follows:-

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

where t = Number of Treatments.

b = Number of sub-blocks.

T = Sum of items with same treatment as missing item

B = Sum of items in same block replicate (plants 1-7 or 8-14 in sub-block) as missing item.

S = Sum of all observed items.

The total degrees of freedom for each analysis of variance carried out was reduced according to the number of missing values calculated, one degree of freedom being deducted for each calculated missing value.

The analyses of variance were calculated according to the method prescribed by Snedecor (21).

The 't' tests were also performed according to the method prescribed by Snedecor (21). That is to say

$$t = \frac{\bar{x}}{s_{\bar{x}}}$$

where t = 'Students' t.

$\bar{x}$ = Difference between means.

$s_{\bar{x}}$ = Standard deviation of mean difference.

The graph of tiller production was prepared by dividing the total number of tillers for each root treatment, for the particular date, by the number of plants that gave that total. The histogram for herbage yields was prepared by dividing the total for any particular treatment by the number of plants whose combined total gave that yield.

SECTION VI.

RESULTS.

The following points should be kept in mind when the results are being perused:-

(1) Treatment abbreviations used in tables and text:-

C	denotes	no roots amputated i.e. control treatment.
N	denotes	nodal roots amputated.
P	denotes	primary seminal root amputated.
L	denotes	lateral seminal roots amputated.
NL	denotes	nodal and lateral seminal roots amputated.
NP	denotes	nodal and primary seminal roots amputated.
PL	denotes	primary and lateral seminal roots amputated i.e. all seminal roots amputated.

(2) The term herbage yield implies dry weight yield of herbage.

(3) Levels of significance and their abbreviation

-	:	Non-significant	:	-
5% level	:	Significant	:	S
1% level	:	Highly significant	:	SS

(4) The results apply only to perennial ryegrass (*Lolium perenne*) under the particular environmental conditions prevailing during the period of the experiment.

(5) For ease of presentation and to avoid confusion the results are presented under four sub-sectional headings:-

A The effect of the treatments on the survival of plants.

B The effect of the treatments on the tillering of plants.

C The effect of the treatments on the herbage yield of plants.

D Summary of results.

A. <u>THE EFFECT OF ROOT AMPUTATION AND FERTILIZER TREATMENTS ON THE SURVIVAL OF PERENNIAL RYEGRASS : LOLIUM PERENNE.</u>

There were fourteen treatments in all comprised of two sets of seven root treatments, superphosphate being applied to one set whilst no superphosphate was applied to the other set of seven root treatments.

There were three root treatments, irrespective of the superimposed fertilizer treatments, which showed obvious effects of the treatments over the experimental period in so far as the death of plants under those treatments was concerned.

Plants whose nodal and primary seminal roots were amputated did not survive and had all died within a few days of amputation of the roots. The lateral seminal roots, which remained intact, were unable to supply sufficient water and nutrients to the plants to ensure the continuation of the life of these plants whose nodal and primary seminal roots were amputated. Consequently it is concluded that the plant, in the case of perennial ryegrass, requires further functional roots than the lateral seminal roots for its continued survival.

Two other root treatments, namely nodal roots amputation and nodal and lateral seminal roots amputation treatments, resulted in the death of the plant although not immediately after the amputation of those roots concerned in these two treatments. Plants undergoing these two treatments gradually died during the period of the experiment.

To enable data on death rates of plants undergoing the various treatments, counts of surviving plants were made following on from the third tiller counting date (4th January, 1950) at weekly intervals, data already being available from the first three tiller counts on the death rates up to the third tiller counting date.

With the other four root treatments (C, P, L and PL.) five plants were damaged during the amputation of the various roots and, over the remaining period of the experiment, a further ten plants died; cause not determined. However, it was considered advisable to use a missing plot estimate for the above fifteen missing plants because no reason for the treatments causing their death could be seen. However, with the two treatments, nodal roots amputated and nodal and lateral seminal roots amputated, when compiling appendices II-V instead of calculating missing values for those plants which died they were given a zero number of tillers. Since the treatments N and NL were obviously bringing about the death of the plants it stood to reason that the numbers of tillers was zero for non-living plants and hence the appendices were drawn up in the manner shown.

In order to determine if there was any treatment differences between nodal roots amputation and nodal and lateral roots amputation treatments in the presence and absence of superphosphate with respect to numbers of surviving plants Table XIV was drawn up.

TABLE XIV. Number of plants surviving at various observation dates.

Treatments	Fertilized		Non-Fertilized	
Date	N	NL	N	NL
2nd December, 1949	31	32	32	30
16th December, 1949	27	30	29	30
4th January, 1950	21	28	24	25
11th January, 1950	15	17	16	16
18th January, 1950	10	9	7	6
25th January, 1950	6	4	3	5
1st February, 1950	1	-	-	2
8th February, 1950	-	-	-	-

The differences between treatments were not marked, and accordingly the data given in Table XIV was transposed to length of life of the plants in days and appendix I was compiled. Using the data in this appendix the following Table was drawn up.

TABLE XV. Mean average length of life in days of treatments N and NL fertilized and non-fertilized.

Grouping Criteria		Groups	
By Blocks	I 85.125	VII 76.875	XIII 91.875
	II 86.625	VIII 89.250	XIV 88.375
	III 85.750	IX 86.875	XV 96.250
	IV 74.500	X 87.500	XVI 88.625
	V 84.250	XI 86.000	
	VI 85.750	XII 91.000	
By Fertilizer	Non-fertilized	86.844	
	Fertilized	86.234	
By Different Root Treatments	N 85.672		
	NL 87.406		

The differences were still not very obvious but neverthless an analysis of variance was performed and the results so obtained are given in Table XVI.

TABLE XVI. Analysis of variance of length of life of treatments N and NL fertilized and non-fertilized.

Source of Variation	df	Sums of Squares	Mean Square	F	Required Ratio	Significance
Between Blocks	15	3247.18	217.16	0.370	5% : 2.41	-
Between Fertilizer	1	27.50	27.50	0.047	5% : 4.54	-
B x F (Error i)	15	8797.12	586.47			
Between Treatments	1	96.25	96.25	0.760	5% : 3.94	-
T x F	1	54.08	54.08	0.427	5% : 3.94	-
T x B } T x B x F } Error (ii) }	94	11899.67	126.59			
Total	127	24121.80				
Standard Deviation = 11.25		Coefficient of Variation = 13%				

The difference between fertilizer treatments was not significant and it is concluded that the application of superphosphate at five cwt. per acre caused no significant increase, or decrease, in the length of life of the plants.

The difference between root treatments was non-significant, nor was there a significant treatment by fertilizer interaction. Consequently, it is concluded that the two root treatments (N and NL) cause no significant difference in the length of life of plants, these two root treatments bringing about the death of plants at approximately the same rate. Furthermore, the same applies whether or not superphosphate is applied. Thus the amputation of the lateral seminal root, in addition to the amputation of the nodal roots, does not bring about a significantly earlier death of plants as compared to plants whose nodal roots only are amputated.

From the above results, plants were able to survive on their primary seminal root or all seminal roots up to 112 days and the average days of life from the time of sowing was almost three months or more exactly 86½ days.

B. THE EFFECT OF ROOT AMPUTATION AND FERTILIZER TREATMENTS ON THE NUMBER OF TILLERS OF PERENNIAL RYEGRASS.

In this study, on the effect of various root amputation treatments on tiller development, only six of the seven root treatments could be counted at the first three observations. The seventh root treatment, nodal and primary roots amputated, did not survive and could not give any tiller numbers at any of the four counts. At the time of the fourth or final count two other root treatments, namely nodal roots amputated and nodal and lateral seminal roots amputated, had no surviving plants and consequently only four root treatments were observed at the final count.

Since the seven root treatments were applied to two fertilizer treatments this gave a total of fourteen treatments. Because of the non-survival of one root treatment only twelve treatments were observed at the first three countings, this being decreased to eight treatments at the final tiller count because of the non-survival of two further root treatments to which the two fertilizer treatments had been applied.

From the tiller numbers obtained at the various counting dates the data was arranged in tables as shown in appendices II-V.

From these appendices the tiller numbers were grouped as shown in tables XVII-XX. These tables give the mean average number of tillers per plant at the various dates of counting, recorded in various groupings.

TABLE XVII. Mean average tiller numbers per plant at 2nd December, 1949.

Grouping Criteria	Groups		
By Blocks	I 6.3333	VII 5.9583	XIII 6.2500
	II 6.0000	VIII 7.5833	XIV 6.7083
	III 6.6250	IX 6.1667	XV 5.9583
	IV 6.5000	X 5.2917	XVI 7.0417
	V 6.4167	XI 5.7917	
	VI 6.9583	XII 6.5417	
By Fertilizer	Non-fertilized	6.2865	
	Fertilized	6.4792	
By Different Root Treatments	C 7.6875		
	N 5.8750		
	P 5.4063		
	L 7.1250		
	NL 5.6094		
	PL 6.5938		

TABLE XVIII. Mean Average tiller numbers per plant at 16th Dedember, 1949.

Grouping Criteria	Groups		
By Blocks	I 14.792	VII 14.417	XIII 16.375
	II 14.250	VIII 16.333	XIV 16.750
	III 19.292	IX 13.708	XV 16.458
	IV 16.458	X 12.875	XVI 14.292
	V 14.458	XI 15.583	
	VI 14.958	XII 14.542	
By Fertilizer	Non-fertilized	15.187	
	Fertilized	15.755	
By Different Root Treatments	C 20.719		
	N 8.859		
	P 15.531		
	L 19.000		
	NL 11.969		
	PL 16.750		

TABLE XIX. Mean average tiller numbers per plant at 4th January, 1950.

Grouping Criteria	Groups		
By Blocks	I 40.417	VII 49.000	XIII 59.917
	II 38.167	VIII 48.458	XIV 67.292
	III 52.000	IX 34.083	XV 58.542
	IV 44.083	X 36.542	XVI 53.333
	V 33.042	XI 48.417	
	VI 36.417	XII 46.833	
By Fertilizer	Non-fertilized	44.917	
	Fertilized	48.354	
By Different Root Treatments	C 68.344		
	N. 9.953		
	P 55.109		
	L 65.109		
	NL 24.094		
	PL 57.203		

TABLE XX. Mean average tiller numbers per plant at 15th March, 1950.

Grouping Criteria	Groups		
By Blocks	I 62.313	VII 78.125	XIII 88.313
	II 62.875	VIII 72.875	XIV 101.188
	III 83.625	IX 51.063	XV 89.750
	IV 74.813	X 59.813	XVI 80.000
	V 53.625	XI 72.750	
	VI 59.813	XII 71.313	
By Fertilizer	Non-fertilized	69.961	
	Fertilized	75.320	
By Different Root Treatments	C 79.219		
	P 68.063		
	PL 66.031		
	L 77.250		

It was observed that differences occurred between groups and it was necessary to determine whether or not these were statistically significant. An analysis of variance was carried out for each tiller counting date and Tables XXI-XXIV prepared.

TABLE XXI. Analysis of Variance of tiller numbers as at 2nd December, 1949.

Source of Variation	df	Sums of Squares	Mean Square	F	Required Ratio	Significance
Between Blocks	15	108.6	7.24	1.034	5% : 2.41	-
Between Fertilizer	1	4.5	4.50	0.643	5% : 4.54	-
B x F (Error i)	15	105.0	7.00			
Between Treatments	5	262.8	52.56	10.365	5% : 2.25 1% : 3.10	SS
T x F	5	26.1	5.22	1.027	5% : 2.25 1% : 3.10	-
T x B T x B x F Error (ii)	332	1683.7	5.07			
Total	373	2190.7				
Standard Deviation = 2.25				Coefficient of Variation = 35.27%		

TABLE XXII. Analysis of Variance of tiller numbers as at 16th December, 1949.

Source of Variation	df	Sums of Squares	Mean Square	F	Required Ratio	Significance
Between Blocks	15	825.7	55.05	1.87	5% : 2.41	-
Between Fertilizer	1	4.9	4.09	0.17	5% : 4.54	-
B x F (Error i)	15	442.4	29.49			
Between Treatments	5	6221.1	1244.22	27.19	5% : 2.25 1% : 3.10	SS
T x F	5	180.6	36.12	0.79	5% : 2.25 1% : 3.10	-
T x B T x B x F Error ii	337	15416.9	45.75			
Total	378	23091.6				
Standard Deviation = 6.76				Coefficient of Variation = 43.69%		

TABLE XXIII. Analysis of Variance of tiller numbers as at 4th January, 1950.

Source of Variation	df	Sums of Squares	Mean Square	F	Required Ratio	Significance
Between Blocks	15	36017.8	2401.2	3.97	5% : 2.41 1% : 3.50	SS
Between Fertilizer	1	1129.2	1129.2	1.86	5% : 4.54	-
B x F (Error i)	15	9083.4	605.6			
Between Treatments	5	182378.2	36475.6	74.97	5% : 2.25 1% : 3.10	SS
T x F	5	1950.4	390.1	0.80	5% : 2.25 1% : 3.10	-
T x B T x B x F Error ii	333	162016.8	486.54			
Total	374	392575.8				
Standard Deviation = 22.06		Coefficient of Variation 47.3%				

TABLE XXIV. Analysis of Variance of tiller numbers as at 15th March, 1950.

Source of Variation	df	Sums of Squares	Mean Square	F	Required Ratio	Significance
Between Blocks	15	46769	3118	4.018	5% : 2.41 1% : 3.50	SS
Between Fertilizer	1	1838	1838	2.368	5% : 4.54	-
B x F (Error i)	15	11645	776			
Between Treatments	3	8266	2755	3.597	5% : 2.65 1% : 3.88	S
T x F	3	1173	391	0.510	5% : 2.65	-
T x B T x B x F Error ii	203	155492	766			
Total	240	225183				
Standard Deviation = 27.68		Coefficient of Variation = 38.12%				

As can be seen from Tables XVII-XX there were differences between blocks. The variation due to blocks was not significant at the first two tiller counts (See Tables XXI and XXII), but the last two tiller counts (See Tables XXIII and XXIV) did give a statistically highly significant difference. The experimental design then has allowed for some of the variation due to uneveness in soil fertility.

All four tiller counts showed that the fertilizer treatment was not significantly different from the non-fertilizer treatment at the various stages of plant development. There was, however, a trend for the fertilized plants to have increased tiller numbers and, if more plants had been treated and observed, it may have been possible to get a significant fertilizer effect on tillering of plants through reducing variation due to random environmental factors and individual plant peculiarities. However, the results obtained showed that the plants did not tiller significantly more in response to 5 cwt. of superphosphate over tillering of plants to which no superphosphate was applied. It must be kept in mind however, that a measurement by number does not indicate the relative size of tillers. For example were the tillers larger on those plants to which superphosphate was applied or not? This point was not investigated by eye observation but the herbage yields show that superphosphate must have resulted in larger tillers. (See Page 91).

As a result of no fertilizer effect with respect to tillering, when comparing the effect of the various root treatments on tillering, all plants undergoing the same root amputation treatment were combined irrespective of the fertilizer treatment. In this way the mean average tiller numbers, as shown in Tables XVII-XX, for the various root treatments were obtained. These mean average tiller numbers at the various dates of counting are plotted on a graph shown in figure 5.

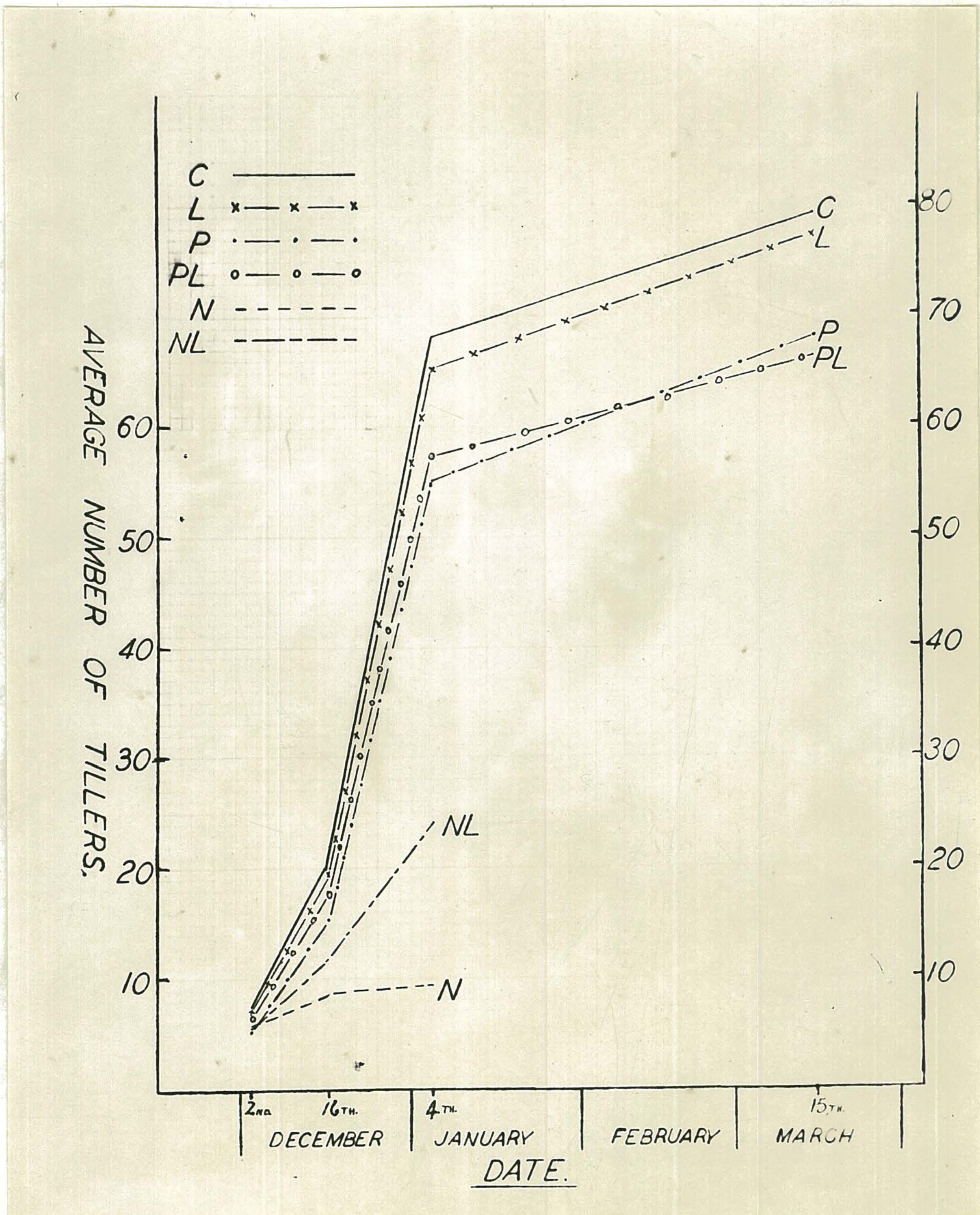

FIGURE 5. Graph of the mean average tiller numbers for the various root treatments at the four tiller counting dates.

Figure 5 shows the tiller development as an average of the sixty-four plants which underwent each root amputation treatment. It will be noticed both from this figure and Tables XVII-XX that the removal of nodal roots markedly reduces tiller numbers, particularly at the latter observations, when compared with the control treatment. The removal of the primary seminal root had a more or less intermediate effect between the two aforementioned treatments whereas lateral seminal root amputation had little depressing effect on tillering when compared with the control treatment.

As a result of the observed depressing effect of the root treatments on tillering when comparing treatment means, and significant treatment differences in the analysis of variance Tables (See Tables XXI-XXIV), the following analyses of variance, comparing root amputations as a whole with control, were calculated.

TABLE XXV. Analyses of variance comparing control with root amputations for the various dates of tiller counting.

Date	ANALYSES OF VARIANCE						
	Source of Variation	df	Sums of Squares	Mean Square	F	Required Ratio	Significance
2nd Dec. 1949.	Treatment total	5	262.8				
	Control V Root Amputations	1	130.7	130.7	25.78	5% : 3.87 1% : 6.72	SS
	Within Root Treatments	4	132.1	33.02	6.51	5% : 2.40 1% : 3.38	SS
	Error ii (See Table XXI)	332	1683.7	5.07			
16th Dec. 1949.	Treatment total	5	6221.1				
	Control V Root Amputations	1	2088.7	2088.7	45.8	5% : 3.87 1% : 6.72	SS
	Within Root Treatments	4	4132.4	1033.1	22.7	5% : 2.40 1% : 3.38	SS
	Error ii (See Table XXII)	337	15416.9	45.75			

TABLE XXV. (Continued)

Date	ANALYSES OF VARIANCE						
	Source of Variation	df	Sums of Squares	Mean Square	F	Required Ratio	Significance
4th Jan. 1950.	Treatment total	5	182378				
	Control V Root Amputations	1	36187	36187	74.1	5% : 3.87 1% : 6.72	SS
	Within Root Treatments	4	146191	36548	74.8	5% : 2.40 1% : 3.38	SS
	Error ii (See Table XXIII)	333	162017	486.5			
15th Mar. 1950.	Treatment total	3	8266				
	Control V Root Amputations	1	3692.6	3692.6	4.86	5% : 3.89 1% : 6.76	S
	Within Root Treatments	2	4573.4	2286.7	2.98	5% : 3.04 1% : 4.71	—
	Error ii (See Table XXIV)	203	155492	766			

From the above Table it is to be observed that root amputations as a whole are highly significantly different from the control treatment. Moreover, the variation within the root amputations was greater than the experimental error variance and this then indicates that the various root treatments have significantly different effects.

By the use of the mean number of tillers for each root treatment (See Tables XVII-XX) the mean differences were obtained for use in the 't' test so as to enable statistical examination of the differences between means of each root treatment and all other root treatments. The standard deviation was calculated for each tiller counting date so that the standard deviation of the mean difference could be obtained for the 't' tests performed for each tiller counting. 't' was thus calculated in the following manner:-

$$\bar{sx} = \frac{2s}{n}$$

$$t = \frac{\bar{x}}{\bar{sx}}$$

s = Standard deviation.

n = Number of plants undergoing each treatment.

$\bar{sx}$ = Standard deviation of the mean difference.

$\bar{x}$ = Difference between means.

The results of the 't' test are shown in the following Table:-

TABLE XXVI. RESULTS OF THE 't' TEST AND SIGNIFICANCE OF DIFFERENCE BETWEEN MEANS OF THE VARIOUS ROOT TREATMENTS COMPARED IN PAIRS AT THE VARIOUS DATES OF TILLER COUNTING.

Date Required Ratio Treatment Comparisons		2nd December, 1949. 5%:1.979, 1%:2.615 't'	 Signif.	16th December, 1949. 5%:1.979, 1%:2.615 't'	 Signif.	4th January, 1950. 5%:1.979, 1%:2.615 't'	 Signif.	5th March, 1950. 5%:1.979, 1%:2.615 't'	 Signif.
Control	V nodal roots amputated	4.55	SS	9.97	SS	14.98	SS	N Dead	
"	V primary sem. root amputated.	5.73	SS	4.36	SS	3.39	SS	2.28	S
"	V Lateral sem. roots amputated	1.41	—	1.45	—	0.83	—	0.40	—
"	V nodal & lateral sem. roots amputated	5.22	SS	7.36	SS	11.35	SS	NL Dead	
"	V all seminal roots amputated	2.75	SS	3.34	SS	2.86	SS	2.70	SS
Nodal)	V primary sem. root amputated	1.18	—	5.61	SS	11.58	SS	N Dead	
roots)	V lateral sem. roots amputated	3.14	SS	8.52	SS	14.16	SS	N Dead	
amputated)	V nodal & lateral sem. roots amputated	0.67	—	2.61	S	3.63	SS	NL N Dead	
"	V all seminal roots amputated	1.81	—	6.63	SS	12.12	SS	N Dead	
Primary)	V lateral sem. roots amputated	4.32	SS	2.92	SS	2.57	S	1.88	—
Sem. Root)	V nodal & lateral sem. roots amputated	0.51	—	2.99	SS	7.96	SS	NL dead	
amputated)	V all seminal roots amputated	2.98	SS	1.02	—	0.54	—	0.42	—
Lat. Sem.)	V nodal & lateral sem. roots amputated	3.81	SS	5.91	SS	10.52	SS	NL Dead	
roots amputated)	V all seminal roots amputated	1.33	—	1.89	—	2.03	S	2.30	S
Nodal & Lateral Seminal roots amputated	V all sem. roots amputated	2.47	S	4.02	SS	8.49	SS	NL Dead	

Treatment comparisons will now be dealt with individually on the basis of the results obtained with the 't' test, which tested the significance of the difference between means of the various root treatments.

1. COMPARISON BETWEEN CONTROL AND NODAL ROOTS AMPUTATION TREATMENTS.

The mean number of tillers per plant undergoing these two treatments and the difference between means at various dates of observation were as follows:-

TABLE XXVII. Mean number of tillers per plant and differences between means for treatments C and N.

Date	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Control	7.6875	20.719	68.344	79.219
Nodal Roots Amputated	5.8750	8.859	9.953	——
Differences between means	1.8125	11.860	58.391	
Significance	SS	SS	SS	

The difference between the mean number of tillers of these two treatments was highly significant at the first three observations, and it is assumed that this difference is highly significant at the counting on the 15th March, 1950 as a result of the non-survival of those plants whose nodal roots were amputated. It will be seen in Figure 5 that the amputation of the nodal roots has a marked depressing effect on tiller development. In view of the fact that the nodal roots of a normal plant become the most extensive of the various roots a short while after germination of the seed, under normal environmental conditions, one would expect this reduction in tillering since the amputation of these roots would considerably reduce the root absorbing area, root absorption thus being confined to the seminal roots. This is apparently the underlying cause of the results obtained here, because the amputation of the nodal roots allowed for hardly any tiller development and ultimately caused the death of plants so treated.

2. COMPARISON BETWEEN CONTROL AND PRIMARY SEMINAL ROOT AMPUTATION TREATEMENTS.

The following Table gives the mean number of tillers per plant for the above two treatments and the differences between means at the respective tiller counting dates.

TABLE XXVIII. Mean number of tillers per plant and differences between means for treatments C and P.

Date	2nd Dec. 1949.	16th Dec. 1949	4th Jan. 1950.	15th Mar. 1950.
Control	7.6875	20.719	68.344	79.219
Prim. Sem. Root amputated	5.4063	15.531	55.109	68.063
Differences between means	2.2812	5.188	13.235	11.156
Significance	SS	SS	SS	S

From Table XXVI it will be observed that the first three tiller counts gave a highly significant difference between means of tiller numbers. For the last tiller count the difference between means was significant only to the 5% level of probability. Thus the difference between means becomes less significant with increase in age of the plants undergoing these two treatments.

This change in significance is explained on the following basis. In the early developmental stage of the plant the primary seminal root comprises the bulk of the plant's root system. With increasing age of the plant the nodal roots become more extensive and supply increasing quantities of nutrients to the growing plant. Hence the amputation of the primary seminal root has a greater effect on tiller numbers in the earlier stages of plant growth. The effect of the amputation of this root is masked as the nodal root system becomes more extensive, and the significance of the difference between means becomes less.

3. COMPARISON BETWEEN CONTROL AND LATERAL SEMINAL ROOTS AMPUTATION TREATMENTS.

The mean number of tillers and differences between means are shown in Table XXIX for the plants undergoing the above two treatments at the various tiller counting dates.

TABLE XXIX. Mean number of tillers per plant and differences between means for treatments C and L.

	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Control	7.6875	20.719	68.344	79.219
Lat. Sem. Root Amputated	7.1250	19.000	65.109	77.250
Differences between means	0.5625	1.719	3.235	1.969
Significance	——	——	——	——

At no stage did the lateral seminal root amputation treatment give a significantly different effect on tiller numbers from that of the control treatment. From Figure 5 and Table XXVI it is seen that this treatment resulted in a trend towards reduced tillering of the plants but the difference between the means of this treatment and control failed to reach significance.

When the amputation of the lateral seminal roots was performed it was observed that they were either poorly developed or, as was the case with many of the plants, no lateral seminal roots had developed. However, this was observed to be the case soon after emergence of the plants and poor development at this stage gives no real indication of the extent to which the lateral seminal roots will develop with increasing age of the plants. In the preliminary investigations it was noticed, however, that perennial ryegrass plants at an age of two months had a poorly developed lateral seminal root system (See Page 23).

In the light of the above, it is concluded that the lateral seminal roots are somewhat limited with respect to growth and thus are capable of supplying only a small quantity of nutrients to the plant. When they are amputated their loss is not serious as was shown by the tiller numbers and the statistical analysis of same in this experiment.

In addition to the 't' test results with the comparison under review the analyses of variance results given in Table XXX bear out the contention that the amputation of lateral seminal roots cause a non-significant effect on tillering of perennial ryegrass plants. At all four counts the analyses of variance gave non-significance when lateral seminal root amputations were compared with no lateral seminal root amputations.

TABLE XXX. Analyses of variance comparing lateral seminal roots amputation with no lateral seminal roots amputation for the various tiller counting dates.

Date	ANALYSES OF VARIANCE						
	Source of Variation	df	Sums of Squares	Mean Square	F	Required Ratio	Significance
2nd Dec. 1949.	Treatment total	5	262.8				
	Laterals V no laterals	1	1.4	1.4	0.28	5% : 3.87 1% : 6.72	—
	Within groups	4	261.4	65.35	12.89	5% : 2.40 1% : 3.38	SS
	Error ii (See Table XXI)	332	1683.7	5.07			
16th Dec. 1949.	Treatment total	5	6221.1				
	Laterals V no laterals	1	43.9	43.9	0.96	5% : 3.87 1% : 6.72	—
	Within groups	4	6177.2	1544.3	33.86	5% : 2.40 1% : 3.38	SS
	Error ii (See Table XXII)	337	15416.9	45.75			
4th Jan. 1950.	Treatment total	5	182378				
	Laterals V no laterals	1	1797	1797	3.68	5% : 3.87 1% : 6.72	—
	Within groups	4	180581	45145	92.5	5% : 2.40 1% : 3.38	SS
	Error ii (See Table XXIII)	333	162017	486.5			
15th Mar. 1950.	Treatment total	3	8266				
	Laterals V no laterals	1	256	256	0.34	5% : 3.89 1% : 6.76	—
	Within groups	2	8010	4005	5.26	5% : 3.04 1% : 4.71	SS
	Error ii (See Table XXIV)	203	155492	766			

4. COMPARISON BETWEEN CONTROL AND NODAL AND LATERAL SEMINAL ROOTS AMPUTATION TREATMENTS.

Table XXXI gives the mean number of tillers per plant and the differences between means at the various observation dates for the plants that were under the above two treatments.

TABLE XXXI. Mean number of tillers per plant and differences between means for treatments C and NL.

Date	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Control	7.6875	20.719	68.344	79.219
Nod. & Lat. Sem. Amputated	5.6094	11.969	24.094	
Difference between means	2.0781	8.750	44.250	
Significance	SS	SS	SS	

With this comparison the differences between means were highly significant at the first three tiller countings. Because of the non-survival of the plants of treatment nodal and lateral seminal roots amputated at the fourth tiller counting on March 15th, 1950, it is assumed that this root amputation treatment is highly significantly different from the control treatment.

In view of the type of roots amputated this difference in effect on tiller numbers between these two treatments can be explained on the same basis as was given when the two treatments control and nodal roots amputated were compared (See page 74). The only difference in treatment is that the lateral seminal roots are amputated, in addition to the nodal roots, and since it has been shown that lateral seminal roots amputation causes no significant differences from no lateral seminal roots amputation, then the comparison under discussion can be explained as stated. That is to say, the amputation of the nodal and lateral seminal roots reduces the root absorbing surface considerably, limiting nutrient absorption to the primary seminal root, and thus causes reduced tillering of the plants under this treatment.

5. COMPARISON BETWEEN CONTROL AND PRIMARY AND LATERAL SEMINAL ROOTS AMPUTATION TREATMENTS.

The mean number of tillers per plant and the differences between means for the various tiller counting dates are given in Table XXXII.

TABLE XXXII. Mean number of tillers per plant and differences between means for treatments C and PL.

Date	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Control	7.6875	20.719	68.344	79.219
Prim. & Lat. Sem. Root Amputated	6.5938	16.750	57.203	66.031
Difference between means	1.0937	3.969	11.141	13.188
Significanse	SS	SS	SS	SS

At all four tiller counting dates the differences between means were highly significant. The significance of the mean differences above are similar to those in the comparison between control and primary seminal root amputation treatments except that, with the latter comparison the mean difference on 15th March, 1950 was significant only to the 5% level of probability. (See Page 75). It has already been shown (Page 76) that the lateral seminal roots are only of minor importance (if any) and cause no significant depression in tiller numbers, when amputated, as compared to the untreated or control plants. The depression in tillering is similar in this comparison (C V PL) to the depression in tillering resulting when the primary seminal root is amputated (See Page 75 and Figure 5). Consequently the reduction in tillering that occurs with the primary and lateral seminal roots amputation treatment, compared to the control treatment, is concluded as being almost entirely due to the amputation of the primary seminal root.

With the remaining comparisons the results of the 't' test are accepted with trepidation. We are not testing the difference between means of pairs of treatments at random. The basic mathmatical principle of the 't' test is randomness and the comparisons made here are not selected at random. This objection also applies to the comparisons between control and all other root treatments that have been discussed in (1) to (5) above, but it is felt that the comparisons are justified because we desire to know in what way the various root treatments effect a response in plants as opposed to those that are untreated. However, to what degree the various root treatments affect the plant, e.g. whether or not the amputation of the primary seminal root depresses tillering significantly as much as the amputation of all the seminal roots, is, from this experiment, to be accepted with diffidence. Tukey (25) discusses this problem and states that results obtained when comparing individual means in the analysis of variance should be accepted with reservation.

6. COMPARISON BETWEEN NODAL ROOTS AMPUTATION AND PRIMARY SEMINAL ROOT AMPUTATION TREATMENTS.

The following Table shows the mean number of tillers for the above two treatments and the difference between means at the various dates of tiller counting.

TABLE XXXIII. Mean number of tillers per plant and differences between means for treatments N and P.

Date	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Nodal Roots Amputated	5.8750	8.859	9.953	
Prim. Sem. Root Amputated	5.4063	15.531	55.109	68.063
Difference between means	0.4687	6.672	45.156	
Significance	—	SS	SS	

On the 2nd December, 1949 (first tiller count) there was no significant difference, but the difference between means at the second and third tiller counts was highly significant there being a smaller number of tillers developed under the nodal roots amputation treatment. The remaining tiller count is assumed to give a highly significant difference since no plants undergoing the nodal roots amputation treatment survived until the final count on the 15th March, 1950.

This indicates, then that, in the early stages of plant development, the nodal roots and primary seminal root amputations had the same effect on tiller development, and thus it is believed that at the time of the first tiller counting the two root systems were of approximately equal extent and importance in supplying nutrients to the plants. With increasing age of the plants the nodal root system becomes more extensive than the primary seminal root and supplies increasing amounts of nutrients to the plants. Hence, where only the primary seminal root is amputated, the loss of this root is of less importance than where the nodal roots are amputated, and thus the former root treatment allows increased numbers of tillers to develop whereas the continual amputation of the nodal roots finally results in the death of the plants.

7. COMPARISON BETWEEN NODAL ROOTS AMPUTATION AND LATERAL SEMINAL ROOTS AMPUTATION TREATMENTS.

TABLE XXXIV. Mean number of tillers per plant and differences between means for treatments N and L.

Date	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Nodal Roots Amputated	5.8750	8.859	9.953	
Lat. Sem. Roots Amputated	7.1250	19.000	65.109	77.250
Difference between means	1.2500	10.141	55.156	
Significance	SS	SS	SS	

The differences between means given in Table XXXIV were highly significant at the first three counts and, again, it is presumed to be highly significant at the fourth count. The nodal roots amputation treatment depressed tillering to a greater degree than the lateral seminal roots amputation treatment. Since lateral seminal roots amputation treatment was not significantly different from control, whilst nodal roots amputation treatment was highly significantly different from control, it was to be expected that the difference in tiller numbers with the two treatments, here compared, to be significantly different. Statistical analysis of the results prove this to be so. Hence, because the amputation of the nodal roots reduces tiller numbers more than the amputation of the lateral seminal roots, one comes to the conclusion that the nodal roots are of greater importance with respect to tillering than the lateral seminal roots, once the former have developed. This conclusion is understandable when one considers that the lateral seminal roots are usually not extensive, whereas the nodal roots, after appearance, rapidly grow and are soon of great importance in supplying nutrients for plant growth.

8. COMPARISON BETWEEN NODAL ROOTS AMPUTATION AND NODAL AND LATERAL SEMINAL ROOTS AMPUTATION TREATMENTS.

The relevant data on the mean number of tillers per plant and differences between means for these two treatments is given in Table XXXV.

TABLE XXXV. Mean number of tillers per plant and differences between means for treatments N and NL.

Date.	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Nodal Roots Amputated.	5.8750	8.859	9.953	
Nod. & Lat. Sem. Roots Amputated	5.6094	11.969	24.094	
Difference between means	0.2656	3.110	14.141	
Significance	—	S	SS	

The comparison of the above two treatments gave a non-significant difference between means at the first tiller count, with significance to the 5% level at the second tiller count, and reaching the 1% level of significance at the third tiller counting date. This result would have been better understood if the nodal and lateral seminal roots amputation treatment had depressed tillering more than the amputation of the nodal roots. However, in actual fact the opposite occurred.

The only difference in treatment, apart from the removal of the lateral seminal roots with treatment NL eight days after the first nodal roots were amputated, was that the nodal roots were removed on different days only once, namely nodal roots of treatment NL on 20th December, 1949 and nodal roots of treatment N on 22nd December, 1949. It is difficult to see how this could have a bearing on the results obtained, since this difference was significant on the 16th December, 1949 which was before the difference in the time of amputation of the nodal roots occurred.

Until such time as further investigation is carried out to elucidate this problem the writer is of the opinion that the result obtained in this experiment is due to chance, particularly in view of the fact that the amputation of lateral seminal roots, compared with no amputation of the lateral seminal roots, gave non-significance when examined statistically. (See Table XXX and Pages 75-77).

9. COMPARISON BETWEEN NODAL ROOTS AMPUTATION AND PRIMARY AND LATERAL SEMINAL ROOTS AMPUTATION TREATMENTS:

TABLE XXXVI. Mean number of tillers per plant and differences between means for treatments N and PL.

Date	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Nodal Roots Amputated	5.8750	8.859	9.953	
Prim. & Lat. Sem. Roots Amputated	6.5938	16.750	57.203	66.031
Difference between means	0.7188	7.891	47.250	
Significance	—	SS	SS	

From Table XXXVI it is seen that the amputation of the nodal roots has reduced tillering of the plants more than where all the seminal roots are amputated.

The comparison between these two treatments is similar, with respect to significance of the mean differences, to the comparison between nodal roots amputation and primary seminal root amputation treatments. The mean difference was not significant at the first tiller count, but was highly significant at the second and third tiller counts. The final count is also assumed to give a highly significant difference for the reason that no plants undergoing the nodal roots amputation treatment survived until the fourth tiller counting date.

Since lateral seminal root amputations were shown to be non-significantly different from no lateral seminal root amputations (See Table XXX) there should be no difference in the interpretation of the results obtained with this comparison, and the comparison between nodal roots amputation and primary seminal root amputation treatments. In brief then, the nodal roots, becoming more extensive and supplying more nutrients with increasing age of the plants, when amputated, result in a greater depression of tillering than is the case where all the seminal roots are amputated.

10. COMPARISON BETWEEN PRIMARY SEMINAL ROOT AMPUTATION AND LATERAL SEMINAL ROOTS AMPUTATION TREATMENTS.

In Table XXXVII are given the mean number of tillers per plant and differences between these means for the above two treatments at the various dates of tiller counting.

TABLE XXXVII. Mean number of tillers per plant and differences between means for treatments P and L.

	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Prim. Sem. Root Amputated	5.4063	15.531	55.109	68.063
Lat. Sem. Root Amputated	7.1250	19.000	65.109	77.250
Difference between means	1.7197	3.469	10.000	9.187
Significance	SS	SS	S	—

The difference between means of the abovementioned two treatments was highly significant at the first two tiller counts, significant to the 5% level of probability at the the third tiller count and non-significant at the final tiller count. The amputation of the primary seminal root depressed tiller numbers to a greater degree than did the amputation of the lateral seminal roots. Further, because of the change in the level of significance of the differences between means it is deduced that the difference in effect on tiller production of these two treatments is more pronounced in the early life of the plants. In the early stages, the primary seminal root comprises the major portion of the plant's root system whereas the lateral seminal roots are not very extensive. Consequently the amputation of the former depresses tillering more than does the amputation of the latter. As the plant's age increases the nodal roots take over the functions of the seminal roots, and, since they were not amputated in either of the two treatments here compared, they must have been the most important roots with respect to tillering at the time of the last two tiller counts. Thus at the time of the final two tiller counts the effect of the amputation of the two types of seminal roots on tillering was masked to some extent by the increasing activity of the nodal roots.

Since the amputation of the primary seminal root reduces the number of tillers significantly more than does the amputation of the lateral seminal roots it is concluded (with reservation) that the primary seminal root is of greater importance to tillering of plants than are the lateral seminal roots.

11. COMPARISON BETWEEN PRIMARY SEMINAL ROOT AMPUTATION AND NODAL AND LATERAL SEMINAL ROOTS AMPUTATION TREATMENTS.

The mean number of tillers per plant undergoing these two treatments and the differences between means at the various dates of observation are given in Table XXXVIII.

TABLE XXXVIII. Mean number of tillers per plant and differences between means for treatmens P and NL.

Date	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Primary Sem. Root Amputated	5.4063	15.531	55.109	68.063
Nodal & Lat. Sem. Root Amputated	5.6094	11.969	24.094	
Difference between means	0.2031	3.562	31.015	
Significance	—	SS	SS	

The effects of these two treatments on tillering were not significantly different at the first tiller count but at succeeding counts they were highly significantly different, the final date of counting being presumed so because of the non survival of plants undergoing the nodal and lateral seminal roots amputation treatment until the final tiller count.

In accordance with the comparison between nodal roots amputation and primary seminal root amputation treatments (See Page 80) these differences are of the same significance.

Consequently the conclusion drawn from the results of this comparison is that the primary seminal root is of approximately equal importance to the nodal and lateral seminal roots combined in the early stages of plant growth, but, as the nodal roots develop, then those plants from which the nodal and lateral seminal roots are excised are affected, so that tiller development is less than is the case where plants have only their primary seminal root amputated.

12. COMPARISON BETWEEN PRIMARY SEMINAL ROOT AMPUTATION AND PRIMARY AND LATERAL SEMINAL ROOTS AMPUTATION TREATMENTS.

In Table XXXIX. are given the mean number of tillers per plant and differences between means for the above two treatments at the various tiller counting dates.

TABLE XXXIX. Mean number of tillers per plant and differences between means for treatments P and PL.

Date	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Primary Sem. Root Amputated	5.4063	15.531	55.109	68.063
Prim. & Lat. Sem. Root Amputated	6.5938	16.750	57.203	66.031
Difference between means	1.1875	1.219	2.094	2.032
Significance	SS	—	—	—

The results of the comparison between these two treatments shows a highly significant difference between means at the first tiller count but thereafter the three remaining tiller counts failed to give a significant difference between means. Where all the seminal roots were amputated (treatment PL) there was a smaller depression of the tillering of the plants than was the case where only the primary seminal root was amputated, until the time of the final tiller count when the opposite was the case. As to why the difference between means was highly significant at the first count is not understood. Non-significance at the three remaining tiller counts is in accordance with other results, which indicate that the amputation of the lateral seminal roots produces practically no effect on tillering of the plants (See Table XXX).

13. COMPARISON BETWEEN LATERAL SEMINAL ROOTS AMPUTATION AND NODAL AND LATERAL SEMINAL ROOTS AMPUTATION TREATMENTS.

The following Table gives the mean number of tillers and the differences between means for the above two treatments at each tiller counting date.

TABLE XL. Mean number of tillers per plant and differences between means for treatments L and NL.

Date	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Lateral Sem. Roots Amputated	7.1250	19.000	65.109	77.250
Nodal & Lat. Sem. Roots Amputated	5.6094	11.969	24.094	
Difference between means	1.5156	7.031	41.015	
Significance	SS	SS	SS	

As with the comparison between lateral seminal roots amputation and nodal roots amputation treatments (See Page 81) the mean differences between the two treatments under discussion here were highly significant, and again the final count is assumed to be so because of the non survival of plants which underwent the nodal and lateral seminal roots amputation treatment until the final tiller counting date. From the results it is concluded that the depression in tillering of plants, which had their nodal and lateral seminal roots amputated, was due to the importance of the nodal roots in supplying the bulk of the plant's nutrient requirements. The nodal roots must have caused the effect on tillering of the plants since the treatments differ only in that the nodal roots of one set of plants were amputated.

14. COMPARISON BETWEEN LATERAL SEMINAL ROOTS AMPUTATION AND PRIMARY AND LATERAL SEMINAL ROOTS AMPUTATION TREATMENTS.

TABLE XLI. Mean number of tillers per plant and differences between means for treatments L and PL.

Date	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Lateral Sem. Roots Amputated	7.1250	19.000	65.109	77.250
Prim. & Lat. Sem. Roots Amputated	6.5938	16.750	57.203	66.031
Difference between means	0.5312	2.250	7.906	11.219
Significance	—	—	S	S

The differences between means shown in Table XLI were not significant at the first and second tiller counts, and reached the 5% level of significance at the third and fourth tiller counts. The depression in tiller numbers of plants, whose primary and lateral seminal roots were amputated, below those which had only their lateral seminal roots amputated is concluded as being due, in the main, to the amputation of the primary seminal root. Why the differences between means were not significant at the first two counts of the tillers is not understood. Since it has been shown that the amputation of the lateral seminal roots causes no significant depression of tillering (See Pages 75-77 and Table XXX), and because the lateral seminal roots were amputated with both these two treatments being compared here, it would be expected that the mean differences would be of similar levels of significance to those obtained with the comparison between control and primary seminal root amputation treatments. (See Page 75). However, this was not the case, but there was a trend towards a greater reduction in tillering where all the seminal roots were amputated than where only the lateral seminal roots were amputated, this reduction in tillering becoming significantly different with increased age of the plants.

15. COMPARISON BETWEEN NODAL AND LATERAL SEMINAL ROOTS AMPUTATION AND PRIMARY AND LATERAL SEMINAL ROOTS AMPUTATION TREATMENTS.

The following Table shows the mean number of tillers per plant and differences between means at the various tiller counting dates for the above two treatments.

TABLE XLII. Mean number of tillers per plant and differences between means for treatments NL and PL.

Date	2nd Dec. 1949.	16th Dec. 1949.	4th Jan. 1950.	15th Mar. 1950.
Nodal & Lat. Sem. Roots Amputated	5.6094	11.969	24.094	
Prim. & Lat. Sem. Roots Amputated	6.5938	16.750	57.203	66.031
Difference between means	0.9844	4.781	33.109	
Significance	S	SS	SS	

This comparison gave a mean difference significant to the 5% level at the first tiller count but the mean differences were significant to the 1% level at the second and third tiller count. At the time of the final count of the tillers it is assumed that the difference between means was highly significant because of the non survival of plants, whose nodal and lateral seminal roots were amputated, until that tiller count. These results again bring out the point that the nodal roots are the most important of the various roots by virtue of the reduction in tillering of those plants whose nodal and lateral seminal roots were amputated as compared with those whose primary and lateral seminal roots, were amputated. Moreover, with increasing age of the plants the nodal and lateral seminal roots became more important with respect to tillering of the plants than all the seminal roots, as was shown by the change in the level of significance of the mean differences and the increase in magnitude of the differences between means.

C. THE EFFECT OF ROOT AMPUTATION AND FERTILIZER TREATMENTS ON THE YIELD OF HERBAGE OF PERENNIAL RYEGRASS.

For this study on the effect of the various treatments on the herbage yields of the plants only four of the seven root treatments could be measured. The other three root treatments, nodal roots amputation, nodal and lateral seminal roots amputation, and nodal and primary seminal roots amputation treatments, did not survive until the date of herbage yield measurement. Since the seven root treatments were each carried out in the presence or absence of fertilizer this gave a total of fourteen treatments but, because of the non-survival of three of the root treatments, only a total of eight treatments were measured for herbage yields (C, P, PL and L in the presence and absence of fertilizer).

From the herbage yields obtained the data was compiled as shown in Appendix VI. From this Appendix the herbage yields were grouped in various ways as presented in Table XLIII.

TABLE XLIII. Mean average herbage yield per plant for the whole experimental period.

Grouping Criteria		Groups	
By Blocks	I 21.39	VII 30.97	XIII 29.05
	II 20.57	VIII 25.55	XIV 44.06
	III 27.60	IX 13.30	XV 39.40
	IV 39.73	X 24.20	XVI 33.40
	V 21.34	XI 33.19	
	VI 25.87	XII 34.35	
By Fertilizer	Non-fertilized	26.5834	
	Fertilized	31.5699	
By Different Root Treatments	C 31.3208		
	P 26.5227		
	PL 25.3792		
	L 33.0827		

It was observed that there were obvious differences occurring between the various groups and it was deemed necessary to statistically analyse the results to determine whether or not these differences were significant. Accordingly an analysis of variance was performed and the results so obtained are given in Table XLIV.

TABLE XLIV. Analysis of Variance of herbage yields.

Source of Variation	df	Sums of Squares	Mean Square	F	Required Ratio	Significance
Between Blocks	15	15398.47	1026.56	5.705	5% : 2.41 1% : 3.50	SS
Between Fertilizer	1	1591.36	1591.36	8.843	5% : 4.54 1% : 8.68	SS
B x F (Error i)	15	2699.30	179.95			
Between Treatments	3	2642.55	880.85	2.827	5% : 2.65 1% : 3.88	S
T x F	3	387.62	129.21	0.415	5% : 2.65 1% : 3.38	—
T x B T x B x F Error (ii)	203	63256.90	311.61			
Total	240	85976.20				
Standard Deviation = 17.65			Coefficient of Variation 60.68%			

As can be seen from Table XLIII there were differences between blocks. These differences between blocks were highly significant (Table XLIV) and shows that the experimental design had allowed for some of the variation due to uneveness in soil fertility, and soil heterogeneity.

1. EFFECT OF FERTILIZER TREATMENTS ON HERBAGE YIELDS.

The analysis of variance (Table XLIV) gave a highly significant difference between the fertilizer treatments. Thus the application of five cwt. superphosphate per acre gave a significant increase in yield of herbage from plants so treated, over the non-fertilized plants. All four root treatments increased in yield in the presence of superphosphate. No one root treatment increased in yield upon superphosphate application significantly more than any other root treatment, as proven by the non-significant treatment by fertilizer interaction (T x F). The effect of the fertilizer treatments on mean average yield of herbage for each root treatment is given in the following Table.

TABLE XLV. Mean average yield of herbage for each treatment.

Treatment	Non Fertilized	Fertilized
No roots amputated	27.7956	34.8456
Primary Sem. Root Amputated	23.2688	29.7766
Prim. & Lat. Sem. Roots Amputated	24.9669	25.7916
Lateral Sem. roots Amputated	30.3025	35.8659
Mean average all root treatments	26.5834	31.5699

From the above Table it is seen that the application of superphosphate results in a general overall increase in yield, which is quite marked except with the case of the primary and lateral seminal roots amputation treatment. However, because of the non-significant treatment by fertilizer interaction this deviation is non-significant. Thus, irrespective of the root treatment, the application of 5 cwt. superphosphate per acre resulted in a significantly increased yield of herbage.

Figure 6 gives the mean average herbage yield for the various root treatments in the presence and absence of fertilizer, the mean average herbage yield for each root treatment, the mean average herbage yield for each fertilizer treatment and the mean average herbage yield for all plants of the experiment. From this figure it will be observed what effect the various treatments have on mean average herbage yields of perennial ryegrass.

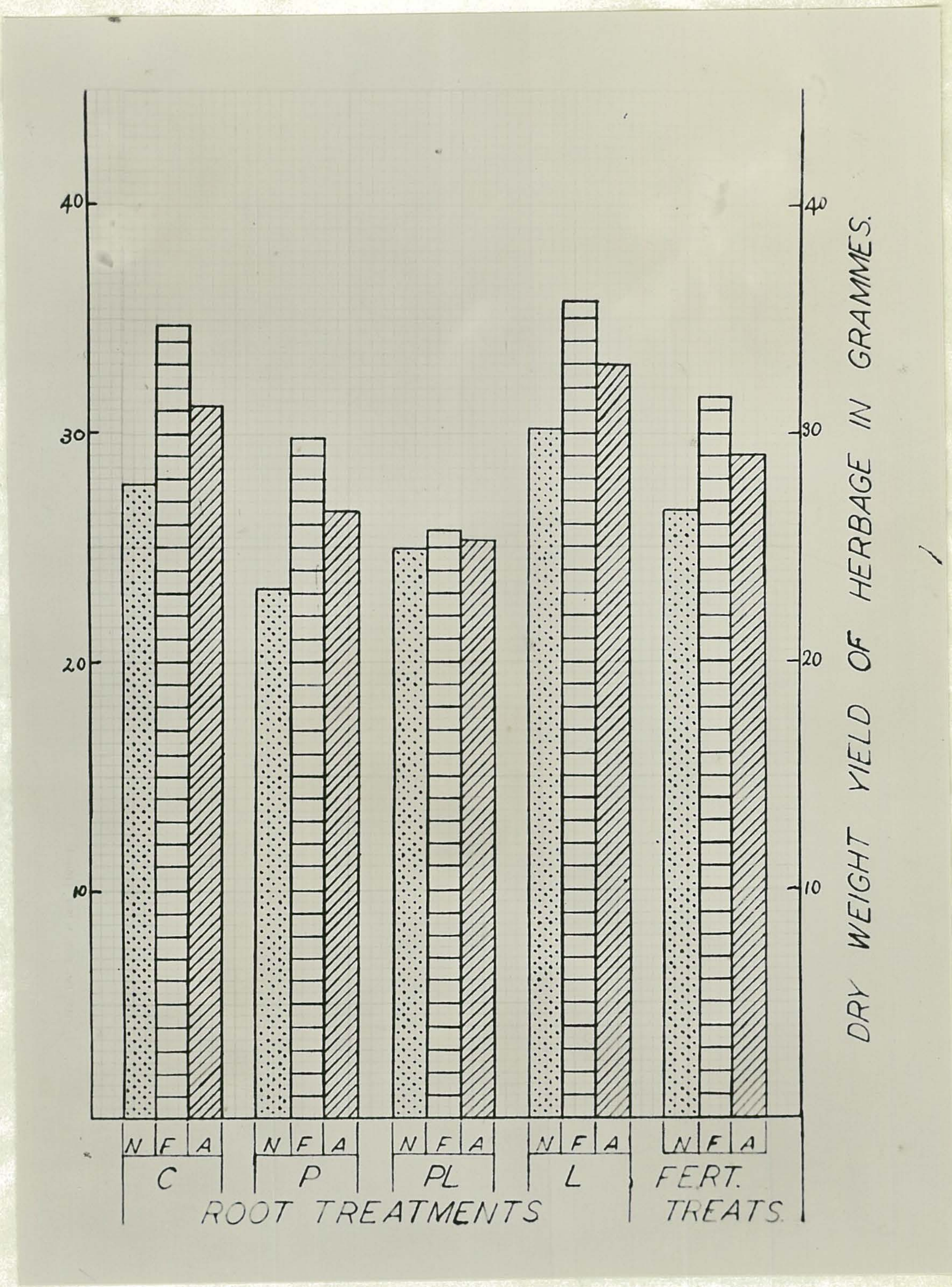

FIGURE 6. Histogram of the mean average dry weight herbage yields in grammes for the various treatments.

N = Non-fertilized.

F = Fertilized.

A = Average of N. and F. for the root treatment or the fertilizer treatment as indicated.

2. EFFECT OF ROOT TREATMENTS ON HERBAGE YIELDS.

From Figure 6 and Table XLII it will be observed that the amputation of the primary seminal root resulted in depressed yields of herbage whilst the amputation of the lateral seminal root caused no depression in yield. As a consequence of these observed varying effects on herbage yields and the significant between treatment variance in the analysis of variance as given in Table XLIV, the following analysis of variance was computed.

TABLE XLVI. Analysis of variance comparing control with root amputations.

Source of Variation	df	Sums of Squares	Mean Square	F	Required Ratio	Significance
Treatment total	3	2642.55	880.85			
Control v Root Amputations	1	429.67	429.67	1.38	5% : 3.89	—
Within Root Treatments	2	2212.88	1106.44	3.55	5% : 3.04 1% : 4.71	S
Error ii (See Table XLIV)	203	63256.90	311.61			

The comparison between control and all other root treatments does not reach significance. A suggested reason for the non-significance of the comparison between control and root treatments is the high experimental error variance and the high coefficient of variation of 60.68% (See Table XLIV). Consequently the variation within groups of plants treated alike is high and is an indication that the plant material used in this experiment varied greatly. It is further suggested that the sums of squares for the control versus root amputations are small because the lateral seminal roots amputation treatment, which has been grouped in with the root treatments, has outyielded the control treatment.

In Table XLVI it will be seen that the variation within root treatments was significantly greater than the experimental error variance indicating that the various root treatments have significantly different effects. In order to determine what root treatments differed significantly further analyses of variance were performed.

The results of the analysis of variance comparing lateral seminal roots amputation with no lateral seminal roots amputation are given in Table XLVII.

TABLE XLVII. Analysis of variance comparing lateral seminal roots amputation with no lateral seminal roots amputation.

Source of Variation	df	Sums of Squares	Mean Square	F	Required Ratio	Significance
Treatment totals	3	2642.55				
Laterals V No laterals	1	6.15	6.15	0.02	5% : 3.89	—
Within Root Treatments	2	2636.40	1318.20	4.23	5% : 3.04 1% : 4.71	S
Error ii (See Table XLIV)	203	63256.90	311.61			

From the above Table it will be observed that lateral seminal roots amputated did not have a significantly different effect from the non-amputation of lateral seminal roots. It will be recalled that the same non-significant effect of the amputation of the lateral seminal roots on the tillering of perennial ryegrass was obtained. (See Page 75). From the comparison in Table XLVII it is concluded that lateral seminal roots amputation treatment is not significantly different from control, nor is primary and lateral seminal roots amputation treatment significantly different from primary seminal root amputation treatment, with respect to herbage yields.

A further analysis of variance was performed comparing primary seminal root amputation with no primary seminal root amputation the results of which are given in the following Table.

TABLE XLVIII. Analysis of variance comparing primary seminal root amputation with no primary seminal root amputation.

Source of Variation	df	Sums of Squares	Mean Square	F	Required Ratio	Significance
Treatment totals	3	2642.55				
Primary V No Primary	1	2500.40	2500.40	8.02	5% : 3.89 1% : 6.76	SS
Within Root Treatments	2	142.15	71.08	0.23	5% : 3.04	—
Error ii (See Table XLIV)	203	63256.90	311.61			

The results obtained show that the effect of the amputation of the primary seminal root is significantly different from that obtained where the primary seminal roots are not amputated.

Therefore the amputation of the primary seminal root reduces the yield of plants significantly. This then leads to the conclusion that the primary seminal root amputation treatment is significantly different from the control treatment, and that the primary and lateral seminal roots amputation treatment is significantly different from the lateral seminal roots amputation treatment.

Because the lateral seminal roots amputation treatment was not significantly different from the control treatment, it is also concluded that the primary and lateral seminal roots amputation treatment is significantly different from the control treatment, and that the primary seminal root amputation treatment is significantly different from lateral seminal root amputation treatment. To summarise, the following Table gives the significance of differences in effect on herbage yields between the various root treatments compared in pairs.

TABLE XLIX. Significance of differences in effect on herbage yields between the various root treatments compared in pairs.

Treatment Comparisons	Significance
Control V Primary Sem. Root Amputated	Significant
" V Prim. & Lat. Sem. Roots Amputated	Significant
" V Lateral Sem. Roots Amputated	Non-significant
Prim. Sem. Root Ampd. V Prim. & Lat. Sem. Roots Amputated	Non-significant
Prim. Sem. Root Ampd. V Lateral Sem. Roots Amputated	Significant
Prim. & Lat. Sem. Roots Amputated V Lat. Sem. Roots Amputated	Significant.

Because the variation between treatments was significant only to the 5% level of probability in the analysis of variance of herbage yields, as given in Table XLIV, and because of the method of determining the significance for between pairs of treatments, the level of significance in Table XLIX has been given as the 5% level, notwithstanding the fact that primary seminal root amputation was significantly different from no primary seminal root amputation to the 1% level of probability. Thus the level of significance given in Table XLIX may tend to be conservative for some of the comparisons.

It has already been mentioned (See Page 90) that the three treatments, nodal roots amputated, nodal and lateral seminal roots amputated, and nodal and primary seminal roots amputated, did not survive until the date of herbage yield measurement. Nodal and primary seminal roots amputation treatment died almost immediately after the amputation of the appropriate roots, whilst the other two treatments, N and NL, died gradually (See Pages 59-62). Even though nodal roots and nodal and lateral seminal roots amputation treatments lived a short while, and produced a small amount of herbage, it is considered that the average quantity produced was small compared to those treatments which survived and for which herbage yields were obtained. Hence it is felt that it is justifiable to say that nodal roots amputation and nodal and lateral seminal roots amputation treatments were significantly different from control, primary seminal root amputation, primary and lateral seminal roots amputation and lateral seminal roots amputation treatments (C, P, PL & L). The same is also taken as applying between nodal and primary seminal roots amputation treatment and the four treatments C, P, PL & L.

However, as to the significance of differences between the three treatments, nodal roots amputated, nodal and lateral seminal roots amputated, and nodal and primary seminal roots amputated, no statement will be made because of the lack of herbage yield criteria.

The conclusion then is that the amputation of the nodal roots, compared with those plants whose nodal roots remain intact, results in a significant reduction in herbage yield.

D. SUMMARY OF RESULTS.

(a) LENGTH OF LIFE.

1. Plants undergoing treatment NP died almost immediately after the amputation of the appropriate roots.

2. Plants undergoing treatments N and NL gradually died after the amputation of the appropriate roots.

3. Plants undergoing treatments C, P, L and PL did not die during the experimental period.

4. An analysis of variance of the treatments N and NL in the presence and absence of fertilizer was performed.

5. There was no significant variation between blocks as measured by length of life in days.

6. Fertilizer did not significantly increase, or decrease, the length of life of plants undergoing treatments N and NL over those plants which were non-fertilized.

7. The length of life of plants undergoing the two root treatments N and NL did not differ significantly.

8. The continual amputation of the nodal roots ultimately results in the death of the plant (Treatments N, NL and NP not surviving until the end of the experimental period).

(b) TILLERING.

1. Plants undergoing treatment NP did not survive until the first tiller count, so no measure of tillering for this root treatment was available.

2. An analysis of variance of the treatments C, P, L, N, PL and NL in the presence and absence of fertilizer was calculated for the first three tiller counts, being reduced to the treatments C, P, L and PL in the presence and absence of fertilizer at the fourth or final tiller count.

3. There was a non-significant variation between blocks at the first two tiller counts but the between block variance became significant at the final two tiller counts.

4. The fertilizer treatment did not significantly differ from the non-fertilizer treatment at any of the four tiller counts.

5. The between treatment variance was significant at all the tiller counts.

6. The control treatment differed significantly from the

remaining root treatments as a whole.

7. There were significant differences within the remaining root treatments.

8. The control treatment differed from the treatment N at all tiller counts, treatment N having brought about a reduction in tillering and ultimately causing the death of the plants.

9. The control treatment differed significantly from the treatment P at all tiller counts, treatment P having brought about a reduction in tillering.

10. The control treatment did not differ significantly from the treatment L at any of the four tiller counts.

11. The control treatment differed significantly from the treatment NL at all tiller counts, treatment NL having brought about a reduction in tillering.

12. The control treatment differed significantly from the treatment PL. Treatment PL also caused a reduction in tillering.

13. The significance of comparisons made in points 14-23 below are to be accepted with reservation because of non-random selection of pairs of treatments.

14. Treatment N was not significantly different from treatment P at the first tiller count but became significantly different at the succeeding tiller counts.

15. Treatment N differed significantly from treatment L at all tiller counts.

16. Treatment N, although not significantly different from treatment NL at the first tiller count, was significantly different at the second and third tiller counts.

17. Treatment N was not significantly different from treatment PL at the first tiller count but differed significantly at the remaining tiller counts.

18. Treatment P differed significantly from treatment L at all but the last tiller count.

19. Treatment P was not significantly different from treatment NL at the first tiller count but was significantly different at the remaining tiller counts.

20. Treatment P differed significantly from treatment PL at the

first tiller count but was non-significantly different at the succeeding tiller counts.

21. Treatment L was significantly different from treatment NL at all tiller counts.

22. Treatment L became significantly different from treatment PL at the third and fourth tiller counts after being non-significantly different at the first two tiller counts.

23. Treatment NL differed significantly from treatment PL at all tiller counts.

(c) <u>HERBAGE YIELDS.</u>

1. Only the treatments C, P, L and PL were measured, the treatments N, NL and NP not surviving until the time of herbage yield measurement.

2. An analysis of variance was performed on yields obtained from treatments C, P, L and PL in the presence and absence of fertilizer.

3. There were significant differences between blocks.

4. There was a significant difference between fertilizer and non-fertilizer treatments. The application of fertilizer increased yield significantly.

5. There was a non-significant treatment by fertilizer interaction. Thus the fertilizer treatments were significantly different irrespective of the root treatments.

6. There were significant differences between root treatments.

7. Control treatment did not differ significantly from the remaining root treatments.

8. Lateral seminal roots amputation treatments did not differ significantly from no lateral seminal roots amputation treatments.

9. Primary seminal root amputation treatments was significantly different from no primary seminal root amputation treatments.

10. Because treatments N, NL and NP gave no measure of herbage production they are assumed to be significantly different from all other root treatments, namely C, P, L and PL.

SECTION VII.

DISCUSSION.

The results obtained apply only to the particular conditions under which the experiment was conducted.

There was a lack of association and competition with other species, particularly clovers; the soil did not become markedly consolidated because of intercultivation; there was no trampling by stock; and yields were measured by clipping. With respect to the latter point marked differences undoubtedly occur between grazed and clipped swards but, as to whether or not differences do occur with single spaced plants, as in this experiment, is questionable. The clipping of leaf production was effected only twice, approximately three and five months after sowing, and this is considerably different from good grazing management of establishing pastures. A further condition of the experiment is that it was conducted over a period of five months and, although some treatments did not survive, other treatments were still surviving, with the consequence that no indication of the long term effects of certain of the treatments on perennial ryegrass plants could be obtained. Moreover, it must also be realised that the experiment was laid down in the spring which, in the Manawatu, is not the normal time of sowing of pastures.

Even though the conditions were not similar to those that appertain under natural pasture conditions it is, nevertheless, felt that similar results would be obtained under a normal pastural environment.

DISCUSSION AND CRITICISM OF THE EXPERIMENTAL METHOD.

The design of the experiment proved to be satisfactory for the obtaining of statistically evaluated information on the effect of the various treatments on survival, tillering and herbage yields of perennial ryegrass plants. However, with the use of a split-block design, the fertilizer treatments could not be compared as accurately as the root treatments since less replication of the former was provided, but this was of lesser importance because the experiment was primarily concerned with the root treatments. The experimental design also allowed for some of the variation due to soil heterogeneity.

The coeficient of variation for tiller numbers varied between 35% and 47% and in the case of herbage yield it reached almost 61%. The high coefficients of variation, which occurred in this experiment, are an indication that the plant material varied greatly and, in order to have improved the efficiency of the experiment, this variation would have had to have been reduced. It is suggested that the following points may have been observed in an effort to decrease this variation within the plant material. It has already been mentioned (Page 47) that the seed used was the most uniform available, having been harvested from a single plant, but the paternal parent of the seed was unknown. Corkill (26) mentions that variation would be reduced by the use of seed produced by a known cross. A further aid towards the reduction of variation may have been to select plants, for all the various treatments, which had emerged at the same time. It would have been possible to proceed along this line if more plants per plant position had been sown, and if a simple means of identifying those seedlings, which emerged at the same time, had been available. Another means, that may be suggested, is to select plants for the treatments on the basis of evenness of growth up till the time of the commencement of the treatments. In this experiment, however, the rubber discs were applied soon after the emergence of the plants and 12 to 14 days before the root treatments commenced. Some selection was effected in that plants were selected for evenness of growth up till the time of application of the rubber discs, but only a small number of seedlings were available per plant position. Consequently the degree of selection possible was somewhat limited. If selection of plants according to stage of growth is to be resorted one must not overlook the possibility of the human factor bringing about a biased selection.

Failing selection on the basis of evenness of growth at the commencement of the treatments, data re tiller numbers of the individual plants at that time would be useful in that analyses of covariance would be possible. In this way early variation in plant growth may be allowed for. Unfortunately, it was not realized at the commencement of this experiment that data on relative growth at the time the treatments were begun would have been invaluable.

The method of fertilizer application proved to be satisfactory, causing no deleterious effects on germination. Moreover, the fertilizer was situated in a zone into which both the nodal and seminal root systems were capable of rapid penetration.

The amputation of the various roots presented no great difficulties, provided it was carried out with care. The use of rubber discs undoubtedly aided not only rapid identification of the two different root systems, but also the amputation of the nodal roots. The soil above the rubber discs was maintained in a drier condition than the surrounding soil and as a consequence, when the nodal roots had to be exposed for amputation, the removal of the soil around the base of the plant was facilitated. A minor difficulty that did occur was that the central hole in the rubber disc, being of such a size as to enable the disc to be applied, allowed some nodal roots to grow through it. As a result, those nodal roots that did so, had to be distinguished from the internode between the seminal root system and the base of the plant. Some method of sealing the gap would overcome this difficulty and facilitate the method of amputation of the nodal roots.

Difficulty was also experienced when counting the tillers in so far as distinguishing one tiller from the next. The human factor again applies but it is felt that, because the same difficulty of identification of tillers applied to every plant, no one treatment was favoured more than any of the remaining treatments. Moreover, the root treatments were distributed randomly in each block and it was not possible to recognize accurately how the plants were treated, except by reference to the experimental plan. This difficulty was most evident at the last two tiller counts when the tiller numbers were highest.

The technique of measurement of herbage yields allowed for little error to occur. The main difficulty was the tendency for the samples to absorb moisture from the air during weighing. It was felt, however, that this did not influence the results because all weighings were completed rapidly on the chainomatic balance and that each sample was similarly affected. Since the plants, on the average, were quite an appreciable size, some difficulty was experienced in ensuring that all plants were cut to the same height. A small difference in cutting height would have resulted in large differences in herbage weights and so considerable care had to be exercised when the plants were being clipped.

DISCUSSION OF THE RESULTS.

When analyses of variance of survival of plants, tiller numbers and herbage yields were carried out the statistical significance of the differences in effects of the fertilizer and root treatments varied. The results so obtained enabled conclusions to be made.

FERTILIZER TREATMENTS.

The application of superphosphate at the rate of five hundred weight per acre did not significantly increase the length of life of those plants which underwent those root treatments that enabled data on survival of plants to be obtained. The root treatments so concerned were nodal roots amputated and nodal and lateral seminal roots amputated (N and NL). Of the remaining five root treatments, treatments C, P, L and PL were still living at the end of the experimental period irrespective of the fertilizer treatment. Treatment NP died soon after the roots were amputated and no data was taken of the death rate of the plants so treated. As a result, nothing definite can be stated concerning the effect of fertilizer in prolonging the life of plants which underwent these five root treatments. Further experimentation designed to evaluate the importance of superphosphate in prolonging, or otherwise, the life of perennial ryegrass plants under the abovementioned five root treatments is thus required.

The application of superphosphate at the above rate did not significantly increase the number of tillers, irrespective of the root treatments, as compared to those plants to which no superphosphate had been applied. It did, however, result in a highly significant increase in herbage yield, irrespective of the root treatments. Since the final tiller count was taken four days after the final measurement of herbage yield one would conclude that the fertilizer application has brought about an increase in the size of tillers, rather than an increase in tiller numbers. It would thus appear that herbage yield, measured in terms of dry matter, gives a better indication of the plant's response to the application of superphosphate than does the number of tillers.

The treatment by fertilizer interaction was non-significant in the analysis of variance of the herbage yields. Thus the superphosphate application to one root treatment produced yields in accordance with those from the other root treatments. That is to say, the application of superphosphate results in an increased yield approximately proportional to the non-fertilized root treatment yield, rather than increasing the yield of, say, one root treatment and not the other root treatments. Thus the effect of superphosphate is independent of the root treatment to which it is applied and does not offset any deleterious effects of one root treatment any more than it does with the other root treatments.

As a consequence of the observed fertilizer effects in conjunction with the root treatments, it appears that the various roots are all concerned with the uptake of phosphate rather than that one type of root is specifically concerned in the absorption of phosphate. It still remains to be investigated, in so far as the writer is aware, as to whether or not this also applies to the other essential elements.

ROOT TREATMENTS.

The various root treatments had varying effects on survival of plants, tiller numbers and herbage yields. The between root treatments variance was significant in all analyses of variance performed with the three criteria of measurement. When individual pairs of treatments were tested for significance of the difference between mean tiller numbers, by the 't' test, varying levels of significance were obtained, depending on the root treatments so compared. Moreover, the level of significance of the difference between means of the same two treatments in some cases altered from one tiller counting date to the next. In the case of herbage yields differences in significance were obtained when the data was subjected to further analyses of variance in lieu of the 't' test.

The amputation of the three different types of roots had significantly different effects on the plants, irrespective of the fertilizer treatment. The remainder of the discussion is confined to the effect of the amputation of these three different types of roots, even though, with some of the treatments (PL, NL and NP), there was a combined amputation of two of these different types of roots.

LATERAL SEMINAL ROOTS.

The amputations of the lateral seminal roots were observed to have a non-significant effect on the length of life of perennial ryegrass plants, as proven by the fact that the treatments N and NL did not differ significantly, and that the other root treatments, except treatment NP, were still living at the conclusion of the experiment. This conclusion is also substantiated by the fact that perennial ryegrass plants were unable to survive on the lateral seminal root only (treatment NP, which had all roots other than the lateral seminal roots amputated, did not survive).

By analyses of variance, comparing no lateral seminal roots amputated with lateral seminal roots amputated, it was shown that the differences in tillering and herbage yield between the two were non-significant. From this it is concluded that the lateral seminal roots amputation treatment (L) causes a non-significant difference in tillering and herbage yield from that treatment where no roots are amputated (control treatment), and also a non-significant difference between treatments PL and P. The results of the 't' tests on tillering also substantiate the above conclusion. Although a comparison of the yields of treatments NL and N could not be made, the differences in tillering between these two treatments were of varying significance. The difference was non-significant at the first tiller counting date, but was significant at the second and third tiller counting date by the 't' test. No cause for the differences in tillering becoming significant with increasing age was evident, and, in view of the comparison of lateral seminal roots amputation with no lateral seminal roots amputation being non-significant, the writer would prefer further investigation on the comparative effect of treatments N and NL to be carried out.

To summarise, the lateral seminal root plays no important role in tillering and herbage production and its loss does not appear to affect the length of life of perennial ryegrass plants.

The results obtained in the amputation experiment would appear to be closely connected with the extent to which the lateral seminal roots develop. Although no observations on root development were made on the plants in the amputation experiment, the preliminary investigations showed that, in comparison to the development of the primary seminal root, the lateral seminal roots were poorly developed. Also, at the time of the amputation of the various roots, it was observed that the lateral seminal roots, when present, had not developed extensively.

PRIMARY SEMINAL ROOT.

In so far as the survival of plants are concerned, the amputation of the primary seminal root only, did not bring about the death of the plants. Unfortunately the experimental period was short and, as to whether or not the plants of treatment P would succumb, before the plants of the control treatment, remains in doubt. Further experimentation is required in order to resolve this point. However, it is to be noted that, when the two treatments N and NP are compared, the latter treatment results in almost immediate death of the plants, whereas the former treatment allows the plants to continue living for a short while. Thus the amputation of the primary seminal root, in addition to the amputation of the nodal roots, has a marked effect on the length of life of perennial ryegrass plants.

The amputation of the primary seminal root depressed tiller numbers significantly from the control treatment. There was also a significant depression in tiller numbers of plants of treatment PL as compared with those of treatment L. Thus the amputation of the primary seminal root brings about a significant reduction in tiller numbers. The amputation of the primary seminal root did not, however, depress tillering as much as those treatments where the nodal roots were amputated, except at the first tiller count at which time the nodal roots had not developed to any great extent.

Using an analysis of variance, comparing primary seminal root amputation with no primary seminal root amputation, the difference in herbage yield was shown to be significant. Thus the reduced yield of the plants whose primary seminal root was amputated was significantly different from the yield of the plants which had no roots amputated (control treatment). The same is also true of the comparison between the two treatments PL and L, the former treatment having a significantly lower mean yield than the latter treatment.

There is an important point with respect to the effect of the amputation of the primary seminal root on survival, tiller numbers and herbage yields of the plants which was not investigated in this experiment. This concerns the stage of growth attained by the plant when the primary seminal root is amputated. It is believed that the amputation of the primary seminal root, before the nodal roots begin to develop, would kill the plant almost immediately, particularly in view of the fact that in this amputation experiment the plants of treatment NP were unable to survive on the lateral seminal roots only. It is further believed that, the more extensive the nodal roots are when the primary seminal root is amputated, the lesser will be the effect of their loss on the plants. In this amputation experiment the primary seminal root was amputated about two weeks after the nodal roots had first appeared. An experiment, in which the primary seminal root is excised at various intervals after emergence of the plant, would help to elucidate this problem.

It is seen from the results that the amputation of the primary seminal root affects tillering and herbage production. The reductions occurring closely follow the observed relative development of the primary seminal root of perennial ryegrass in the preliminary investigations. In the early stage of the plant's life the primary seminal root is more important than the nodal roots, but, as the plant becomes older, the primary seminal root becomes of lesser importance. The loss of the primary seminal root in the early stages of plant growth has a significant effect on tiller production and this effect is still measurable even after some considerable time has elapsed. It is believed that, because there was a reduction in root absorbing surface at a critical stage in the plant's development, the growth of the plant was retarded.

NODAL ROOTS.

The most marked effects on perennial ryegrass plants were observed with those treatments where the nodal roots were continually amputated (treatments N, NL and NP). The amputation of the nodal roots had effects on both survival of plants and tiller numbers which were examined statistically.

With treatments N and NL the continual amputation of the nodal roots ultimately resulted in the death of the plants, whilst with treatment NP the plants quickly died. Thus, where a plant retained all its seminal roots (treatment N) or only the primary seminal root (treatmen NL) it survived up to 3½ months after sowing, but it was incapable of living on only its lateral seminal roots (treatment NP). Moreover, treatments N ahd NL were non-significantly different, emphasising the small, if any, effect on the length of life of perennial ryegrass plants by the lateral seminal roots.

The 't' test results with respect to tillering show that the nodal roots amputation treatment significantly reduces tiller numbers, compared to the no roots amputation treatment, and that the reduction in tillering effected by the nodal and lateral seminal roots amputation treatment is significantly different from lateral seminal roots amputation treatment. It is evident then that the nodal roots do play an important role in tiller development.

An important point concerning the results is that the nodal roots amputation treatment was not significantly different from the primary seminal root amputation treatment at the first tiller counting date but, at subsequent tiller counting dates, the former treatment had effected a significant reduction in tillering from the latter treatment. It is believed that, in the early period of the experiment the nodal roots had not developed to any extent with the result that both the nodal and primary seminal roots were of approximately equal importance and caused approximately equivalent reductions in tiller numbers, upon amputation.
With increasing age the nodal roots became more extensive and

important, and their loss resulted in greater reduction in tiller numbers than was the case where the primary seminal roots were amputated.

No measurement of yield was obtained from those treatments where the nodal roots were amputated and so it is concluded that those plants whose nodal roots are not amputated are capable of producing significantly more herbage than those plants whose nodal roots are amputated.

It had been observed in the preliminary investigations that the nodal roots began to develop soon after emergence of the plant and became increasingly extensive as the plant aged. On the basis of the root absorbing area of the different types of roots, the results obtained in the amputation experiment, upon the loss of the nodal roots, are readily understood.

SECTION VIII.

CONCLUSION.

The object of the investigation was to determine the relative importance of the various roots to perennial ryegrass. This was achieved and, apart from a few minor problems, the results were satisfactorily interpretated.

The preliminary investigations showed that the order of development of the various roots was:-

most developed : nodal roots

intermediately developed : primary seminal root

least developed : lateral seminal roots

The amputation experiment proved that the lateral seminal roots were of very little, if any, importance with respect to tillering, herbage production and length of life of perennial ryegrass plants.

The nodal roots were of greatest importance to perennial ryegrass plants and, when these roots were continually amputated, tillering was much reduced and the plants were unable to persist beyond approximately four months.

The primary seminal root was as equally important as the nodal roots during the early period of the plant's life, but became of lesser importance with increasing age of the plant. The amputation of the primary seminal root resulted in a decreased herbage production and reduced tillering, more so than was the case where the lateral seminal roots were amputated, but not as much as where the nodal roots were amputated. Thus the primary seminal root is of greater importance than the lateral seminal roots to perennial ryegrass, but not as important as the nodal roots, except in the early stage of plant growth.

5 cwt. of superphosphate per acre resulted in a significantly greater herbage production irrespective of the root treatments, but did not significantly increase tillering or prolong the life of perennial ryegrass plants, as compared to those plants to which no superphosphate was applied.

SECTION IX.

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APPENDIX I. Length of life in days of plants of treatments N and NL in the presence and absence of fertilizer.

BLOCK NUMBER	NON-FERTILIZER ROOT TREATMENT		BLOCK TOTALS NON-FERTILIZER	FERTILIZER ROOT TREATMENT		BLOCK TOTALS FERTILIZER	BLOCK TOTALS
	N	NL		N	NL		
I	98	91	357	58	98	324	681
	84	84		84	84		
II	84	91	343	91	91	350	693
	91	77		84	84		
III	84	84	350	98	84	336	686
	84	98		77	77		
IV	91	105	338	58	58	258	596
	98	44		58	84		
V	58	84	324	105	77	350	674
	77	105		77	91		
VI	84	84	336	91	84	350	686
	91	77		84	91		
VII	58	84	324	84	58	291	615
	105	77		58	91		
VIII	77	84	343	91	98	371	714
	91	91		98	84		
IX	105	91	331	91	105	364	695
	58	77		77	91		
X	77	84	329	98	91	371	700
	91	77		84	98		
XI	98	44	303	105	98	385	688
	77	84		91	91		
XII	98	91	350	112	84	378	728
	77	84		98	84		
XIII	91	84	364	84	84	371	735
	84	105		105	98		
XIV	84	91	350	77	84	357	707
	91	84		105	91		

Cont.

Appendix 1 Cont.

XV	91 84	112 91	378	77 105	105 105	392	770
XVI	105 91	112 91	399	77 44	84 105	310	709
	2757	2762	5519	2726	2832	5558	11077
	ROOT TREATMENT TOTALS N.F.		N.F. TOTAL	ROOT TREATMENT TOTALS F.		F. TOTAL	GRAND TOTAL

APPENDIX II. Number of tillers per plant on the 2nd December, 1949.

BLOCK NUMBER	NON-FERTILIZER ROOT TREATMENT						BLOCK TOTALS NON-FERTILIZER	FERTILIZER ROOT TREATMENT						BLOCK TOTALS FERTILIZER	BLOCK TOTALS
	C	N	P	L	NL	PL		C	N	P	L	NL	PL		
I	1	8	5	6	4	6	66	10	7	8	7	6	8	86	152
	8	5	4	9	6	4		10	8	2	8	5	7		
II	10	6	3	8	7	7	82	6	1	2	7	4	3	62	144
	5	6	5	8	8	9		8	7	8	10	3	3		
III	8	3	9	9	2	10	77	11	8	7	9	6	3	82	159
	10	3	3	6	5	9		1	7	6	8	4	12		
IV	9	6	6	7	1	6	63	12	10	9	7	1	7	93	156
	7	5	6	4	0	6		9	4	8	8	8	10		
V	6	6	7	5	4	6	82	4	4	6	9	6	2	72	154
	9	8	7	9	7	8		8	8	6	6	5	8		
VI	6	3	8	5	7	4	78	9	5	5	6	7	11	89	167
	10	8	3	8	6	10		13	7	3	6	8	9		
VII	3	4	6	10	6	6	70	11	8	3	4	3	11	73	143
	8	2	7	7	4	7		8	5	2	5	4	9		
VIII	8	7	5	11	6	7	93	10	8	8	5	9	4	89	182
	7	9	10	9	6	8		11	6	4	8	7	9		
IX	2	2	5	7	4	6	67	10	5	9	6	6	5	81	148
	8	8	6	8	6	5		8	8	3	7	7	7		
X	5	6	5	7	9	4	64	6	6	4	4	5	6	63	127
	6	4	2	7	7	2		6	6	5	4	5	6		
XI	9	3	5	4	0	5	64	9	7	3	8	7	3	75	139
	7	8	6	4	7	6		6	7	5	7	7	6		
XII	7	4	5	7	6	10	79	8	7	3	8	5	5	78	157
	9	8	3	7	8	5		11	7	3	7	5	9		
XIII	8	7	8	7	8	2	73	6	4	5	9	8	5	77	150
	7	6	3	10	6	1		5	6	10	7	4	8		
XIV	8	8	6	7	6	12	89	11	4	3	6	7	4	72	161
	7	6	9	7	7	6		10	6	2	7	4	8		

Cont

Appendix II Cont.

XV	7	6	4	7	7	11	73	8	2	8	7	7	6	70	143
	7	4	3	8	4	5		4	6	7	3	4	8		
XVI	9	7	3	10	5	8	87	6	8	10	8	11	8	82	169
	5	8	7	8	8	9		11	0	5	9	4	2		
	226	184	174	236	177	210	1207	266	192	172	220	182	212	1244	2451
	ROOT TREATMENT TOTALS N.F.						N.F. TOTAL	ROOT TREATMENT TOTALS F.						F. TOTAL	GRAND TOTAL

APPENDIX III. Number of tillers per plant on the 16th December, 1949.

BLOCK NUMBER	NON-FERTILIZER ROOT TREATMENT						BLOCK TOTALS NON-FERTILIZER	FERTILIZER ROOT TREATMENT						BLOCK TOTALS FERTILIZER	BLOCK TOTALS
	C	N	P	L	NL	PL		C	N	P	L	NL	PL		
I	2	13	16	13	8	11	156	25	0	26	31	11	16	199	355
	22	9	24	18	14	6		22	9	10	21	11	17		
II	26	10	3	26	13	21	177	22	4	9	20	6	8	165	342
	11	9	16	9	8	25		21	15	28	23	2	7		
III	32	5	33	24	12	28	247	36	11	21	25	9	14	216	463
	30	7	16	24	12	24		7	12	23	28	6	24		
IV	23	15	23	27	3	13	198	31	0	24	23	0	19	197	395
	23	17	23	10	0	21		23	0	22	21	21	13		
V	9	0	19	8	6	10	168	7	9	15	28	16	5	179	347
	24	14	17	23	17	21		23	11	26	19	6	14		
VI	14	5	21	5	14	17	188	19	8	11	13	13	27	171	359
	25	15	14	25	13	20		17	14	7	9	11	22		
VII	17	0	11	29	10	12	171	39	10	8	9	0	29	175	346
	20	4	22	24	5	17		21	0	6	22	10	21		
VIII	14	11	16	30	11	15	199	20	8	18	10	18	13	193	392
	21	13	17	16	8	27		23	10	13	18	21	21		
IX	9	2	10	15	7	14	140	27	6	17	18	11	10	189	329
	27	0	15	23	7	11		20	12	8	11	25	24		
X	11	13	15	20	21	6	138	20	9	12	20	10	32	171	309
	10	7	3	13	10	9		16	8	8	8	8	20		
XI	25	5	13	19	0	16	182	23	12	11	32	17	6	192	374
	26	11	17	13	13	24		21	12	17	12	23	6		
XII	16	7	17	15	13	6	159	20	14	5	24	11	19	190	349
	20	13	6	22	14	10		34	15	7	13	21	7		
XIII	26	10	19	21	14	11	177	20	16	19	18	15	16	216	393
	19	11	8	22	11	5		19	13	26	21	15	18		
XIV	22	10	1	20	20	28	199	34	5	14	22	18	15	203	402
	11	9	24	20	17	17		25	11	9	12	12	26		

Cont.

Appendix III Cont.

XV	25	7	14	23	19	41	211	22	2	21	20	21	16	184	395
	18	13	9	19	10	13		6	11	25	4	7	29		
XVI	29	14	7	30	11	19	206	16	10	21	17	20	14	185	391
	12	11	15	19	19	20		28	0	13	19	11	6		
	619	290	484	625	360	538	2916	707	277	510	591	406	534	3025	5941
	ROOT TREATMENT TOTALS N.F.						N.F. TOTAL	ROOT TREATMENT TOTALS F.						F. TOTAL	GRAND TOTAL

APPENDIX IV.   Number of tillers per plant on the 4th January, 1950.

BLOCK NUMBER	NON-FERTILIZER TREATMENT						BLOCK TOTALS NON-FERTILIZER	FERTILIZER TREATMENT						BLOCK TOTALS FERTILIZER	BLOCK TOTALS
	C	N	P	L	NL	PL		C	N	P	L	NL	PL		
I	56	19	43	21	10	27	392	64	0	92	110	25	43	569	961
	35	15	72	53	23	18		55	3	41	38	31	67		
II	79	13	4	61	34	52	415	74	15	34	72	18	45	501	916
	26	10	65	11	0	60		42	15	89	60	2	35		
III	97	8	94	54	26	91	674	114	9	62	73	23	54	574	1248
	85	8	50	76	22	63		46	0	54	73	0	66		
IV	61	14	67	102	8	45	519	88	0	70	57	0	61	539	1058
	62	18	51	51	0	40		70	0	71	64	21	37		
V	13	0	64	17	21	32	361	56	11	40	89	0	19	432	793
	40	0	43	64	24	43		70	0	69	48	5	25		
VI	42	22	7	55	35	71	463	42	19	14	59	16	95	411	874
	60	16	41	62	0	52		44	8	21	18	13	62		
VII	74	0	47	72	14	45	508	106	7	23	43	0	99	688	1176
	66	11	59	75	0	45		69	0	86	87	63	85		

Cont.

Appendix IV Cont.

VIII	53	0	48	117	35	55	612	54	11	94	8	28	49	551	1163
	55	23	55	37	24	110		61	12	69	88	40	37		
IX	35	6	38	46	7	34	348	75	6	81	81	21	7	470	818
	63	0	35	65	0	19		45	0	46	13	51	44		
X	59	0	43	63	43	58	352	67	2	43	86	10	84	525	877
	15	9	4	10	0	48		47	10	42	14	32	88		
XI	64	6	75	86	0	60	640	68	21	40	109	33	13	522	1162
	117	0	77	48	49	58		84	18	33	42	37	24		
XII	61	12	49	24	30	29	467	76	27	33	130	35	68	657	1124
	68	0	53	68	27	46		121	20	38	33	28	48		
XIII	92	15	68	80	26	60	636	85	51	89	72	51	68	802	1438
	89	21	29	93	25	38		96	14	93	84	34	65		
XIV	108	9	76	58	40	169	888	125	0	69	102	44	69	727	1615
	58	15	106	109	60	80		88	18	26	81	24	81		
XV	86	9	54	121	36	132	742	75	0	85	70	48	51	663	1405
	64	15	33	94	43	55		30	17	97	73	2	115		
XVI	106	13	23	99	20	64	607	69	0	81	53	47	49	673	1280
	67	16	38	51	24	86		112	0	91	94	54	23		
	2056	323	1611	2043	706	1885	8624	2318	314	1916	2124	836	1776	9284	17908
	TREATMENT TOTALS N.F.						N.F. TOTAL	TREATMENT TOTALS F						F TOTAL	GRAND TOTAL

APPENDIX V. Number of tillers per plant on the 15th March, 1950.

BLOCK NUMBER	NON-FERTILIZER ROOT TREATMENT C	P	PL	L	BLOCK TOTALS NON-FERTILIZER	FERTILIZER ROOT TREATMENT C	P	PL	L	BLOCK TOTALS FERTILIZER	BLOCK TOTALS
I	63	57	31	26	396	82	103	52	128	601	997
	40	89	26	64		63	50	76	47		
II	87	59	61	78	477	86	41	54	86	529	1006
	33	75	69	15		51	97	41	73		
III	111	107	105	63	705	129	69	68	89	633	1338
	103	57	70	89		57	65	74	82		
IV	86	69	54	121	592	101	83	77	64	605	1197
	91	58	50	63		81	81	42	76		
V	20	73	38	24	387	59	50	24	95	471	858
	57	57	47	71		80	77	30	56		
VI	55	53	78	74	472	50	71	112	72	485	957
	72	13	59	68		53	30	76	21		
VII	83	56	53	79	561	117	32	109	50	689	1250
	79	68	58	85		82	98	97	104		
VIII	67	53	67	131	623	62	111	58	12	543	1166
	71	65	127	42		73	84	43	100		
IX	50	43	39	54	358	86	95	14	97	459	817
	44	33	22	73		51	52	46	18		
X	71	51	38	72	404	79	50	97	95	553	957
	20	44	54	54		54	54	103	21		
XI	69	89	69	99	668	81	48	20	127	496	1164
	127	92	67	56		98	37	28	57		
XII	73	58	34	28	469	87	41	82	148	672	1141
	78	67	53	78		142	74	57	41		
XIII	99	89	72	94	642	101	106	81	87	771	1413
	97	38	44	109		110	112	76	98		
XIV	119	100	171	68	862	141	76	84	117	757	1619
	63	129	89	123		103	32	101	103		
XV	94	68	149	142	731	89	98	63	85	705	1436
	71	39	61	107		37	114	132	87		

Cont.

Appendix V Cont.

XVI	11 82	31 44	71 94	113 62	608	74 125	94 107	60 29	67 116	672	1280
	2386	2024	2120	2425	8995	2684	2332	2106	2519	9641	18596
	TREATMENT TOTALS N.F.				N.F. TOTAL	TREATMENT TOTALS F.				F. TOTAL	GRAND TOTAL

APPENDIX VI. Dry matter yield of herbage per plant for the whole experimental period.

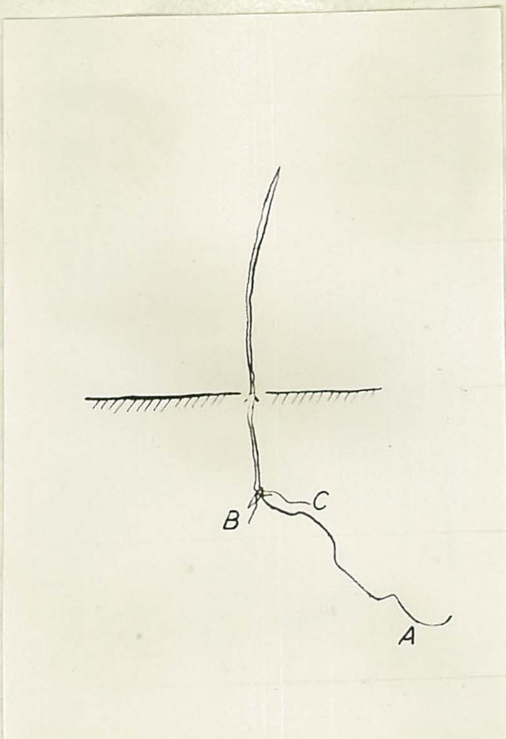
BLOCK NUMBER	NON-FERTILIZER ROOT TREATMENT				BLOCK TOTALS NON-FERTILIZER	FERTILIZER ROOT TREATMENT				BLOCK TOTALS FERTILIZER	BLOCK TOTALS
	C	P	PL	L		C	P	PL	L		
I	29.86	11.63	2.26	3.04	110.68	18.25	61.86	9.44	77.90	231.58	342.26
	4.19	32.02	2.95	24.73		6.88	22.36	30.21	4.68		
II	40.74	12.14	8.72	6.05	120.43	26.72	16.00	23.65	22.04	208.72	329.15
	1.66	28.60	21.53	0.99		31.57	49.14	20.94	18.66		
III	27.27	13.79	20.44	11.29	179.42	69.80	26.88	16.47	49.21	262.24	441.66
	53.78	6.88	22.57	23.40		25.89	20.79	25.76	27.44		
IV	51.13	41.86	24.35	60.64	295.47	72.49	76.49	35.39	34.50	340.27	635.74
	70.19	10.49	15.59	21.22		43.84	18.41	27.83	31.68		
V	6.10	18.81	14.98	4.73	137.59	24.85	14.85	32.81	34.29	203.89	341.48
	23.93	32.15	17.43	19.46		33.31	26.83	5.20	31.75		
VI	8.49	38.29	27.53	35.57	184.07	5.18	28.33	43.17	87.60	229.82	413.89
	29.95	8.02	26.86	9.36		23.10	10.41	28.93	3.10		
VII	20.39	22.22	19.87	43.41	225.33	42.53	7.89	42.33	15.20	270.13	495.46
	17.34	33.78	30.20	38.12		41.94	38.28	38.95	43.01		

Cont.

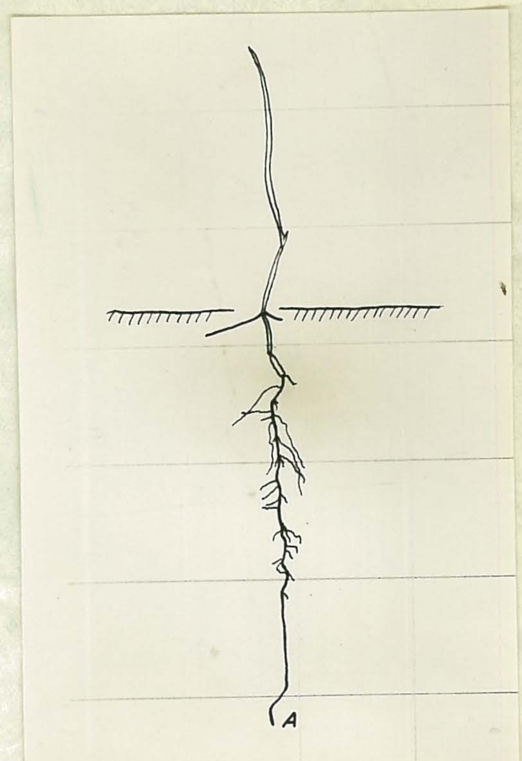
Appendix VI Cont.

VIII	20.18	26.61	16.44	39.54	213.22	39.54	39.64	27.88	0.92	195.58	408.80
	26.49	10.43	55.35	18.18		17.14	24.45	5.77	40.24		
IX	13.70	6.83	6.26	16.26	102.81	23.50	21.39	2.36	41.23	130.04	232.85
	10.52	6.62	4.59	38.03		3.84	22.84	9.51	5.37		
X	30.61	15.63	8.42	33.66	138.81	41.01	17.56	51.32	58.79	248.39	387.20
	3.77	9.05	20.20	17.47		4.53	30.02	38.29	6.87		
XI	27.88	39.79	35.23	41.55	247.22	32.79	32.98	13.13	92.78	283.79	531.01
	25.77	41.11	20.71	15.18		33.77	10.70	17.31	50.33		
XII	41.03	18.57	42.70	1.33	231.89	37.38	25.24	27.98	85.88	317.75	549.64
	31.96	27.71	30.55	38.04		68.32	34.55	19.98	19.42		
XIII	36.49	35.84	35.41	30.88	233.33	34.46	30.34	28.98	4.55	231.42	464.75
	30.32	4.98	23.80	35.61		46.95	35.33	23.17	27.64		
XIV	38.87	42.59	75.88	40.12	394.38	73.90	26.42	28.27	60.44	310.50	704.88
	15.63	57.28	59.44	64.57		62.24	1.81	21.94	35.48		
XV	30.77	39.10	40.50	80.13	318.80	35.66	41.85	15.65	39.58	311.66	630.46
	20.92	24.15	17.22	66.03		9.73	49.33	74.63	45.23		
XVI	56.67	16.80	30.57	45.94	269.22	43.47	45.91	25.92	11.93	265.18	534.40
	42.86	10.83	20.39	45.15		40.84	43.97	12.16	40.97		
	889.46	744.60	798.94	969.68	3402.68	1115.06	952.85	825.33	1147.71	4040.95	7443.63
	TOTALS	ROOT TREATMENT NON-FERTILIZER			N.F. TOTAL	TOTALS	ROOT TREATMENT FERTILIZER			F TOTAL	GRAND TOTAL

APPENDIX VII. Photographs of drawings of various root systems in the early stages of plant development.

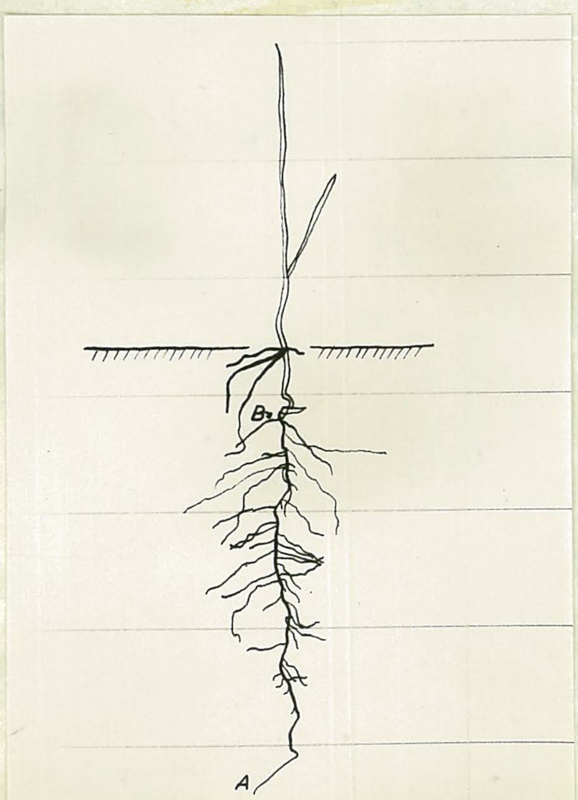


A Per. Rye. Plant
lifted 12. 4.49.

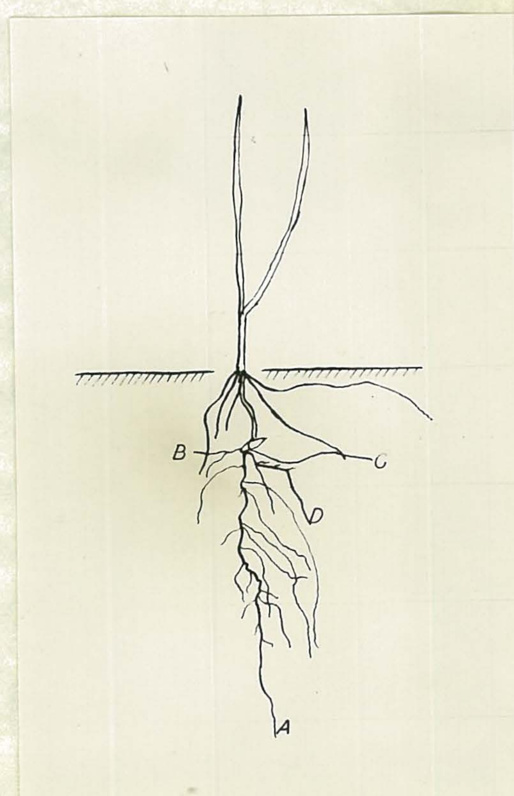


A Per. Rye. Plant
lifted 18. 4.49.

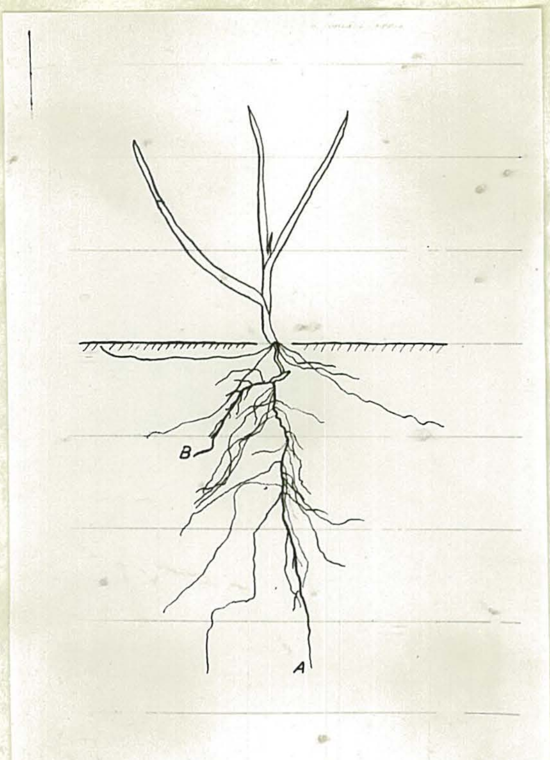
N.B. In all photographs, A denotes the primary seminal root, B, C and D the lateral seminal roots. Distance between the horizontal lines represents a scale of one inch.



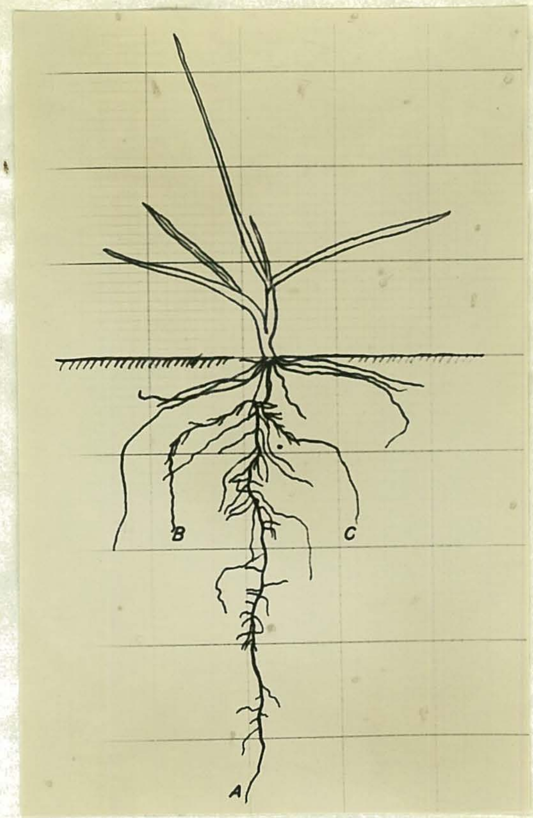
A Per. Rye. plant
lifted 22. 4.49.



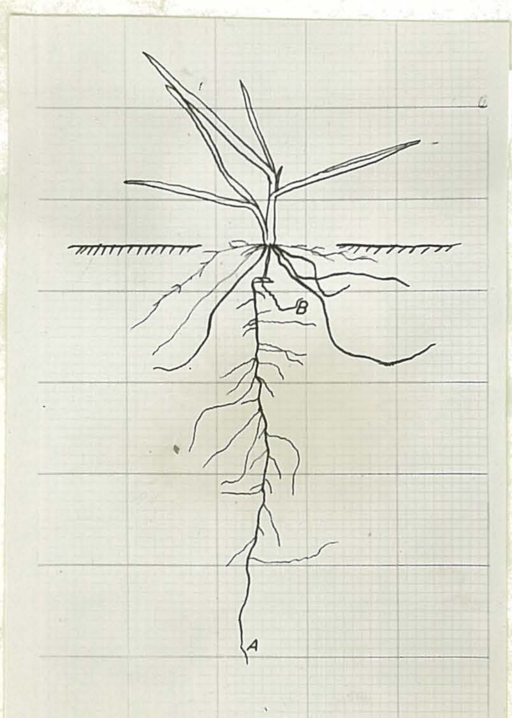
A Per. Rye. plant
lifted 26. 4.49.



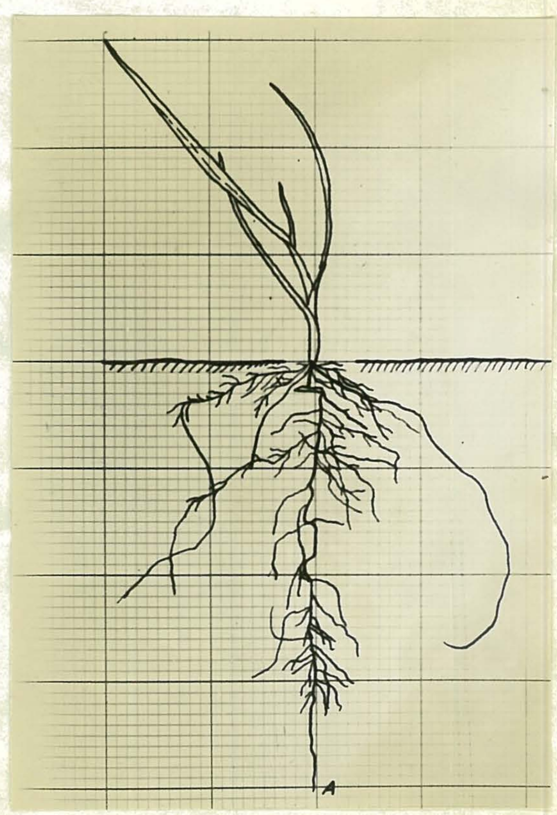
A Per. Rye. Plant
lifted 30. 4.49.



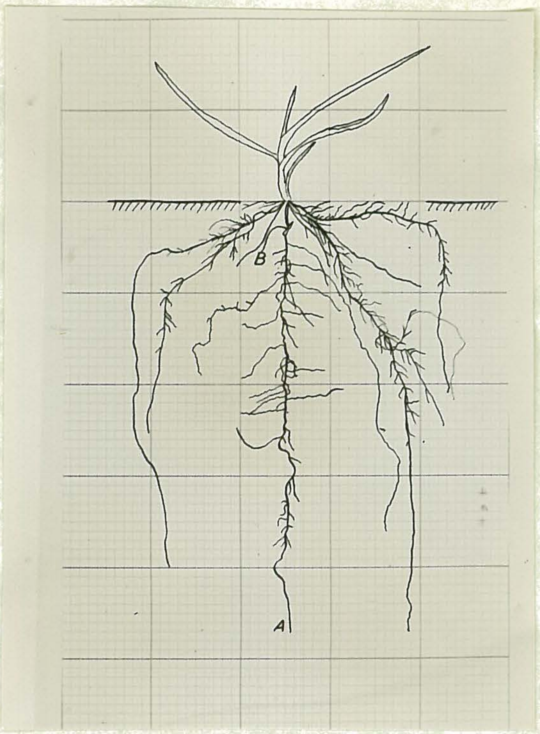
A Per. Rye. Plant
lifted 4. 5.49.

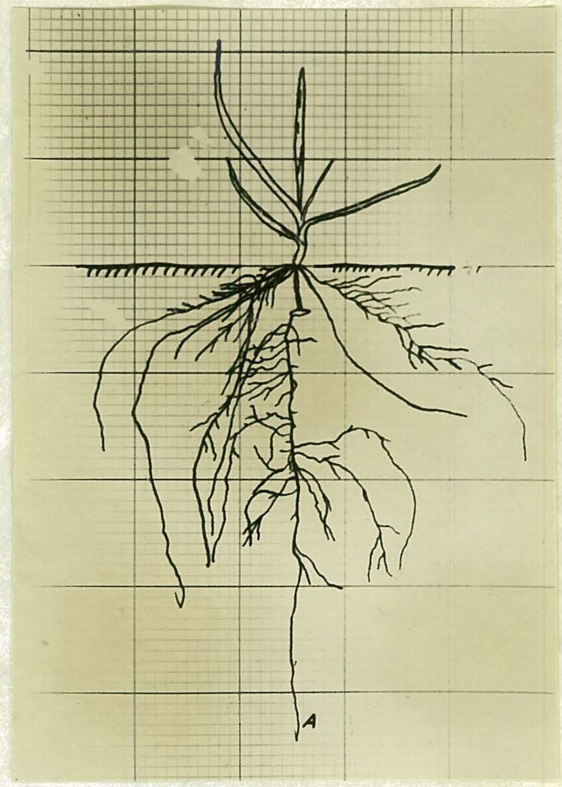


A Per. Rye. Plant
lifted 8. 5.49.



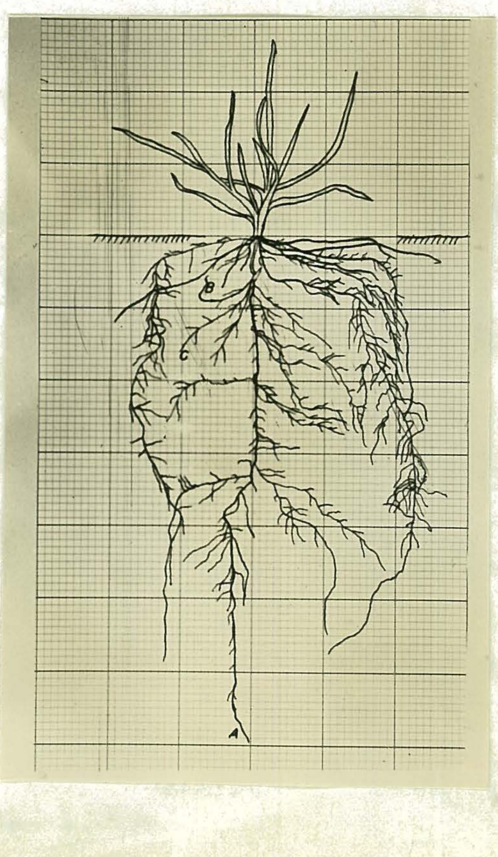
A Per. Rye. Plant
lifted 12. 5.49.



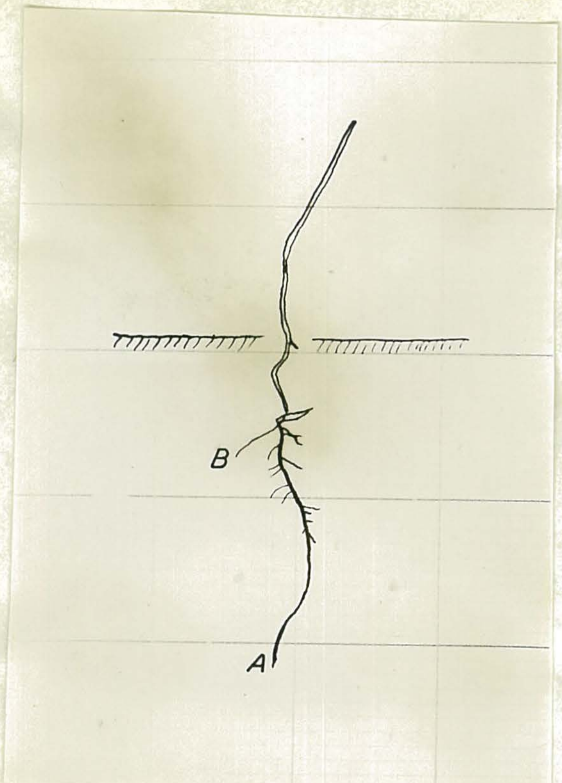


A Per. Rye.Plant
lifted 16. 5.49.

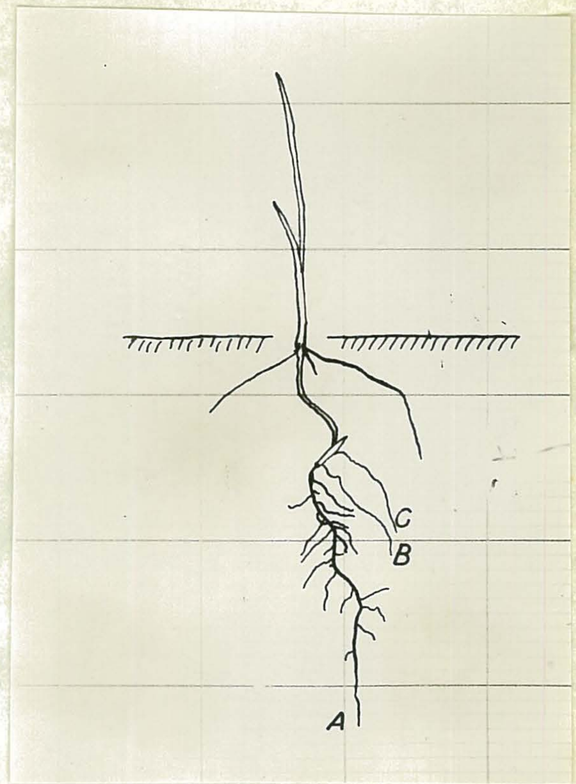
A Per. Rye. Plant
lifted 23. 5.49.



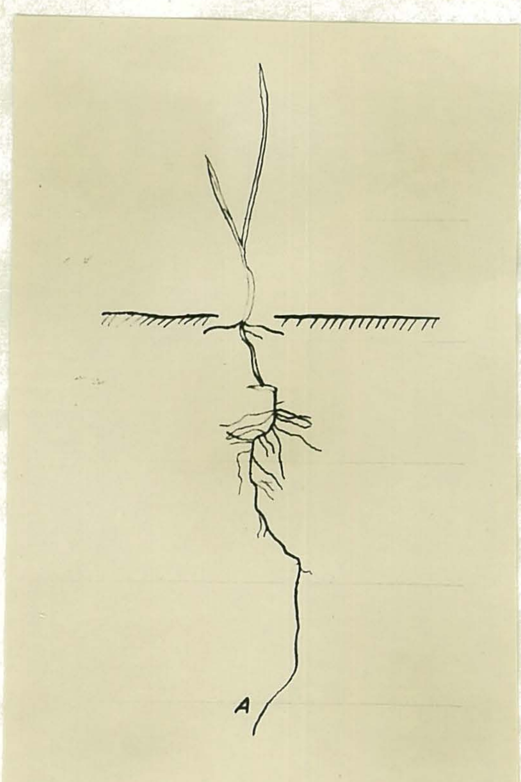
A Per. Rye. Plant



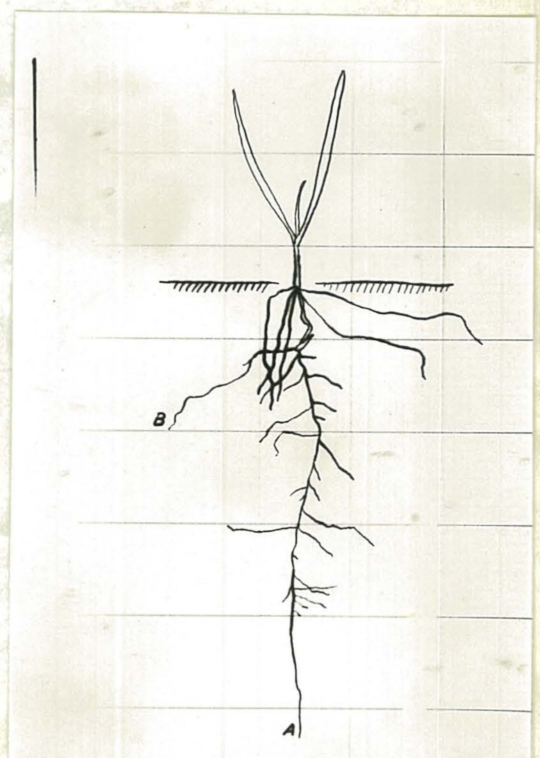
An Ital. Rye. Plant
lifted 12. 4.49.



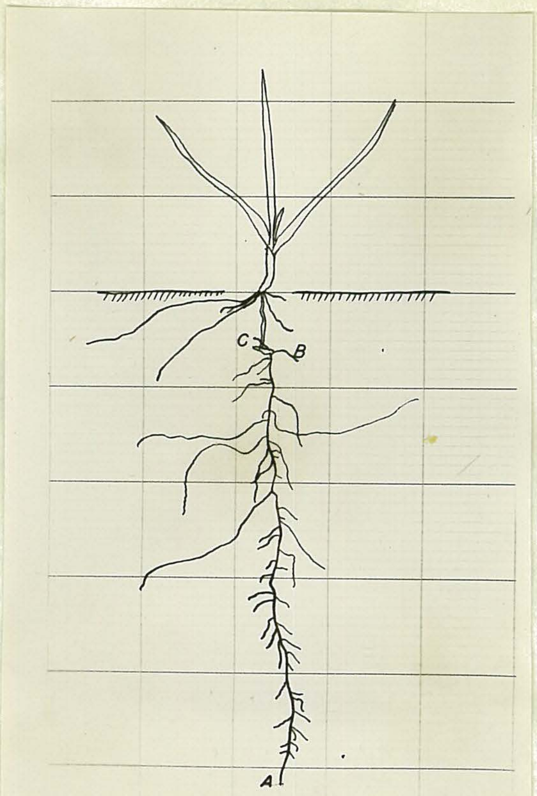
An Ital. Rye. Plant
lifted 18. 4.49.



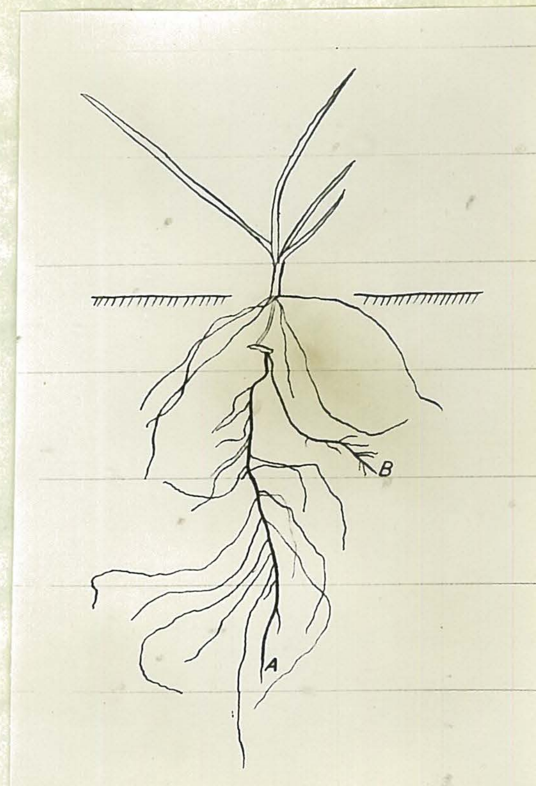
An Ital. Rye. Plant
lifted 22. 4.49.



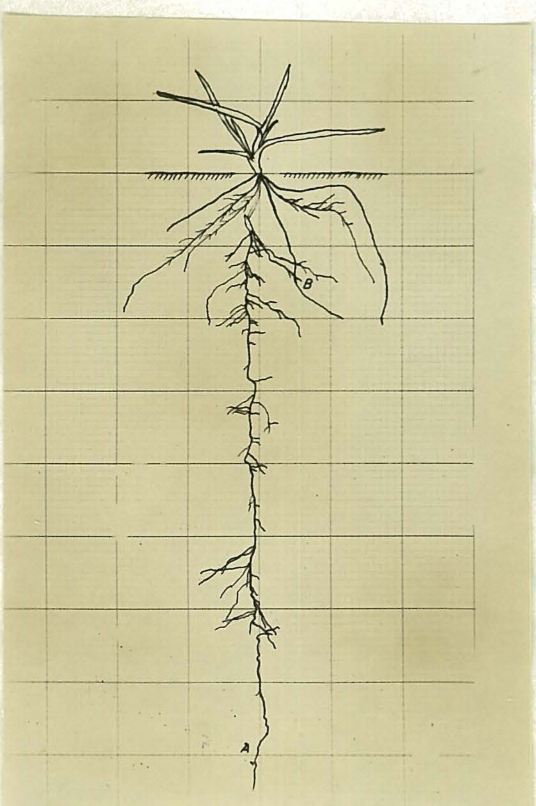
An Ital. Rye. Plant
lifted 26. 4.49.



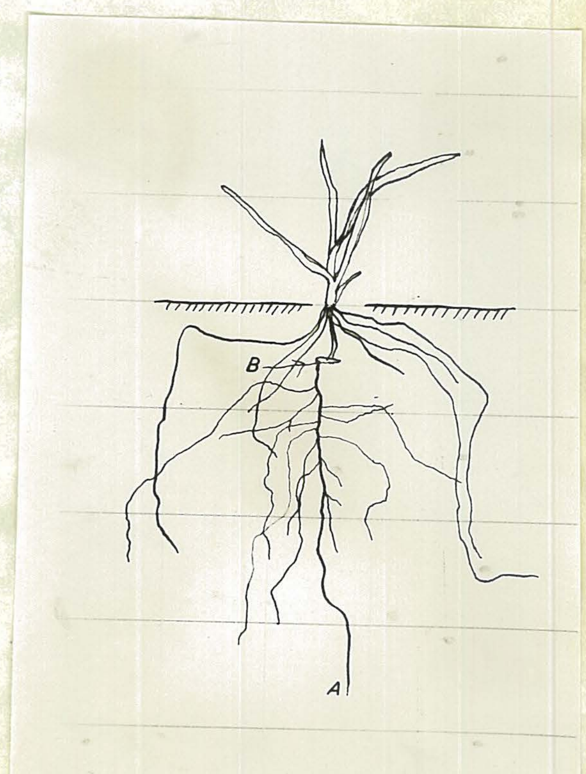
An Ital. Rye. Plant
lifted 30. 4.49.



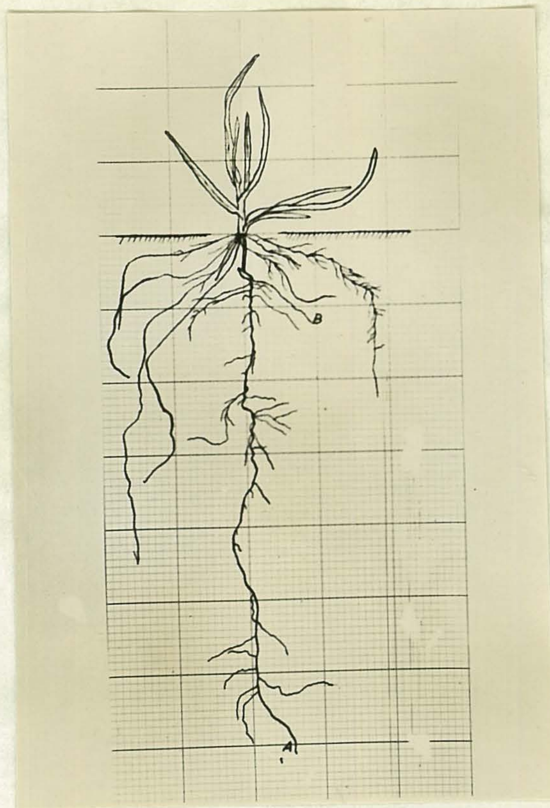
An Ital. Rye. Plant
lifted 4. 5.49.



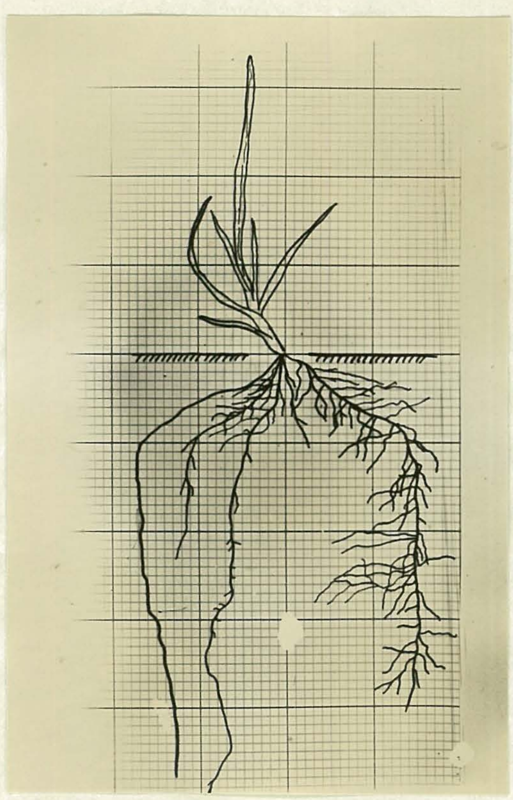
An Ital. Rye. Plant
lifted 8. 5.49.



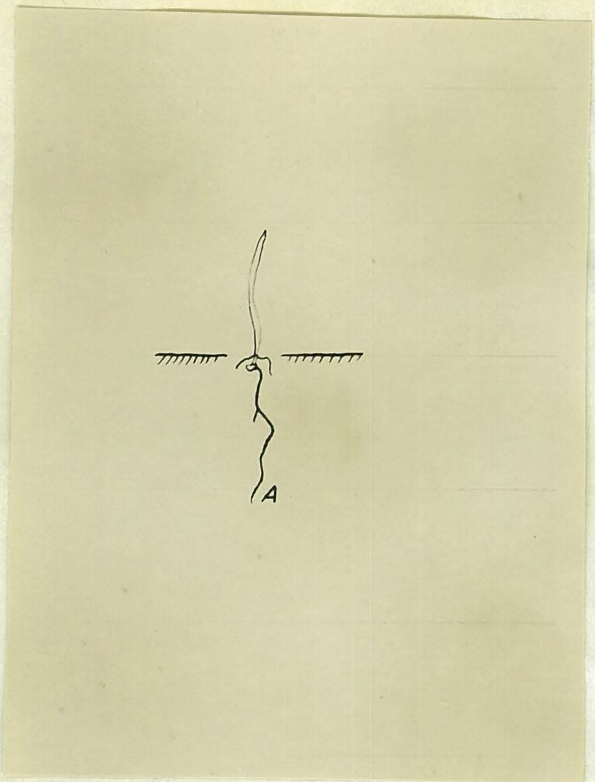
An Ital. Rye. Plant
lifted 12. 5.49.



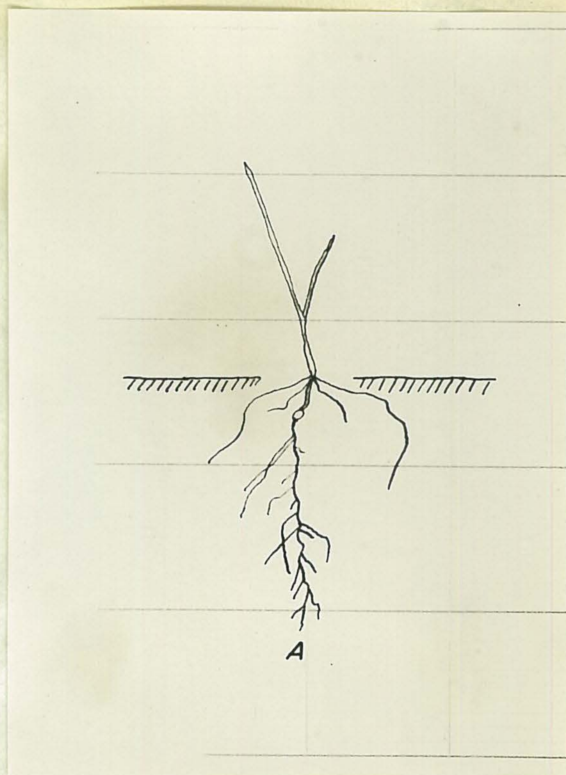
An Ital. Rye. Plant lifted 16. 5.49.



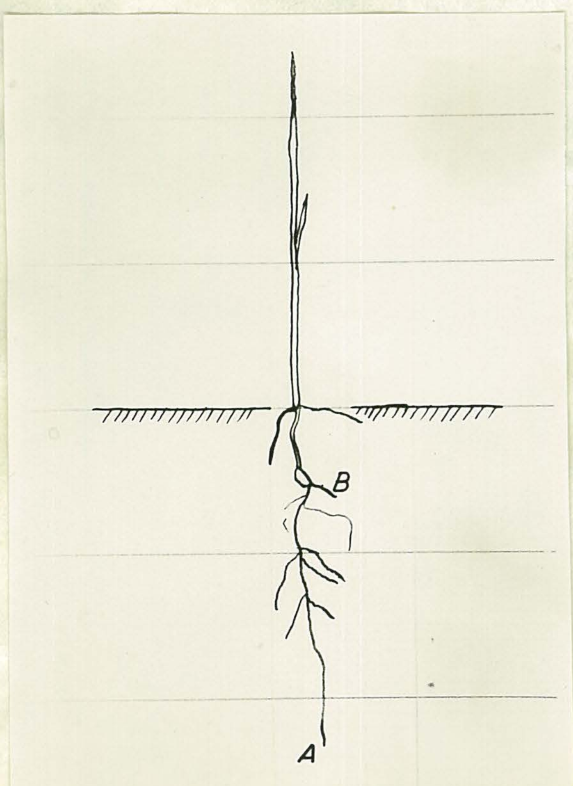
An Ital. Rye. Plant listed 30. 5.49.



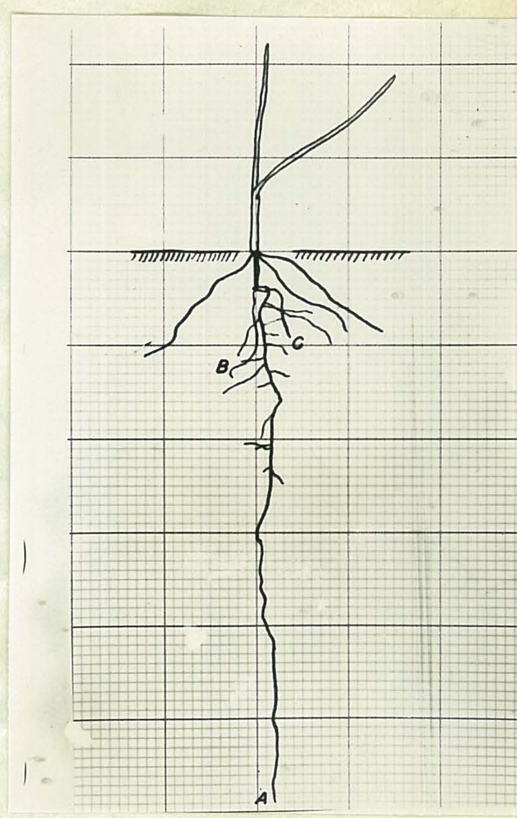
A P. Tuberosa Plant
lifted 22. 4.49.



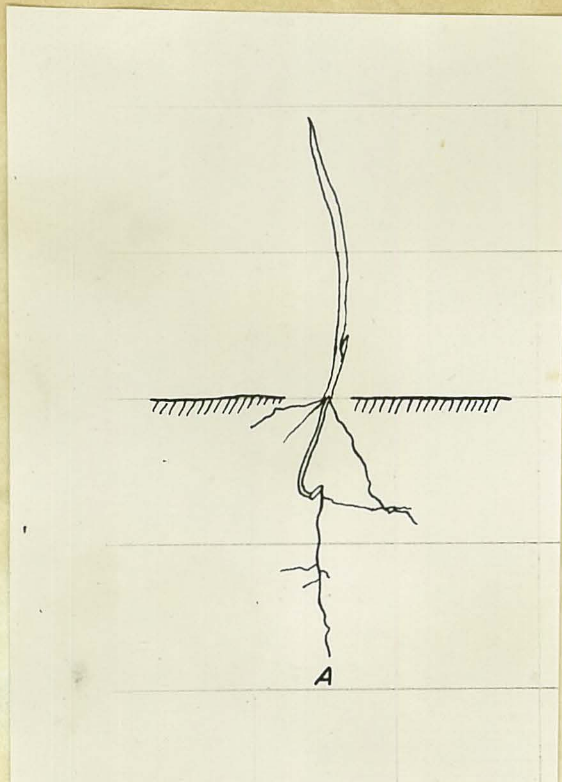
A P. Tuberosa Plant
lifted 26. 4.49.



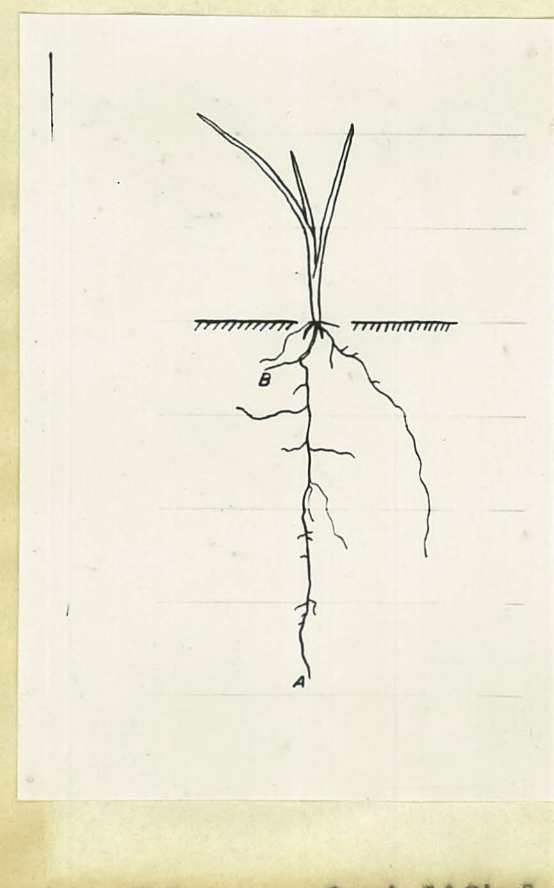
A P. Tuberosa Plant
lifted 30. 4.49.



A P. Tuberosa Plant
lifted 4. 5.49.



A P. Tuberosa plant lifted 8. 5.49.



A P. Tuberosa plant lifted 16. 5.49.