AN INVESTIGATION

into the effect of

SEASONAL ROOT REPLACEMENT

upon

PLANT LONGEVITY

in

PERENNIAL RYEGRASS (LOLIUM PERENNE), ITALIAN RYEGRASS

(L. MULTIFLORUM), TALL FESCUE (FESTUCA ARUNDINACEA)

AND ANNUAL MEADOW GRASS (POA ANNUA).

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SECTION I.

INTRODUCTION

Any reader of the American news magazine, "Time", will know that the editors occasionally publish a "grass roots report" dealing with some current question of public interest. It takes the form of a survey of the fundamental issues involved, and attempts to assess their significance, in-so-far as those issues are known. It is a tacit recognition by a non-scientific body of opinion of the importance of the underground organs to the well-being of a plant, and that these organs are more essential, despite their hidden and inaccessible habitat, than is commonly recognized.

In any study of the growth of pasture plants, a realistic picture will only be obtained if the plant is treated as an entity. The common subdivision of plant tissues into either the aerial leaf and stem portion, or the underground root system, is artificial, for each part of the plant both depends upon and services other parts in many ways. In a discussion of the relative lack of knowledge of leaf chemical constituents, Melville (1954) has stated: "Of the dry tissue of a plant only about 10% comes in through the roots; the remaining 90% is derived from the air through the leaves which, quantitatively, are of very much greater importance as nutritional organs than are roots." A statement such as this does not indicate that the root system has little importance to the plant as a whole. Plant requirements for minerals and nitrogen are at high levels in productive pastures, and the uptake of those nutrients is effected solely through the root system. To a great extent, the 10% of the dry tissue taken in by the roots serves as a pace-maker for the level of activity producing the other 90%. For vigorous leaf production, not only must strong root system capable of fully meeting the plant's nutritional needs for minerals and nitrogen.

Too often, pasture plant studies completely ignore the underground tissues, despite the common knowledge that treatments applied to the leaves can have spectacular effects also upon the root system. The concept of physiological balance between the aerial part and the root system of the plant is based on this inter-dependence of the various plant tissues. In relation to the amount of literature published about top growth in pasture plants, there is a paucity of material dealing with root behaviour. Probably the best-known work has been that of J.E. Weaver and his associates with range grassland in the U.S.A. Weinmann (1948) has written a comprehensive review of the underground development and reserves of grasses, and a total of 125 references exhausts the literature in this field. In New Zealand, Jacques and a group of honours students at Massey College have published results on some aspects of root development in our major grass species. The experiment which is the subject of this thesis, was designed to contribute to this knowledge.

The seasonal nature of the growth of grass root systems is largely unknown, yet from the facts that leaf growth follows a seasonal pattern, and the whole plant is an entire unit with complete interdependence between its parts, it is safe to deduce that the root systems pass through a seasonal growth cycle. The evidence for this, from other studies, which is presented in the review of literature, is based on several different techniques. Some workers have used weight of roots in a fixed volume of soil as their sole criterion, but it is felt that little useful information can be gained in this way. Although a mixed pasture under normal grazing can be examined, it is not possible to measure accurately the contributions to the total weight made by the roots of the component species, while many environmental factors will remain unrecognized in their effects. The logical approach is the study of single entire plants, and this is adopted in the present experiment.

The aim of this work can be stated very briefly. It is to trace out the behaviour of the root systems of certain important grass species over a period of one year, and to determine whether or not this seasonal root behaviour can be related to persistency of individual plants. It is thought that in some species and at certain times of the year, the root system may not be capable of supplying the necessary nutrients in adequate amounts, with a consequent weakening of growth and a possibility of death. It is realized that an experiment of this nature, which is designed to survey a general field rather than to examine some particular character isolated from its complex in the plant, will pose more questions than it answers, and will open up new avenues for further study. Some of these avenues will become evident, or will be indicated, in the text.

SECTION II

REVIEW OF LITERATURE

This review will be presented in three sections, as follows:

(a) literature relevant to the top cutting treatments employed,

(b) literature describing the seasonal nature of growth of grass root systems, and

(c) literature dealing with the use of tetrazolium compounds for studying viability of plant tissues, other than the seed.

A. Top Growth.

The seasonal nature of top growth in grasses, and the control which can be imposed by various environmental factors, has been well established by numerous workers. It is correct to say that the seasonal nature of pasture growth is the basis of pasture management techniques, where the aim is to provide and to utilize herbage in the amounts and at the times when it is required by livestock, with a mininum of wastage.

In New Zealand, the seasonal production of pasture growth under various experimental conditions at Marton and at Ruakura was reported by Hudson et al (1933). Department of Agriculture trials into grassland production levels, and the rate of growth and yield capacity of some of the major pasture species, have been reported by Elliott and Lynch (1942) and more recently by Lynch (1949). In perennial ryegrass at Marton, Lynch found that growth usually commences in early September, is at a maximum in October and November, falls away during December, January and February, and recovers during March or April to levels largely controlled by rainfall. Perennial ryegrass showed great variability between years in its summer and autumn production. Corkill (1950) has discussed the characteristics of the improved strains of grasses and clovers which have been released for commercial use under certification. He says: "...... it will be realized that the prime objective in the plant improvement programme has been to obtain increase in production and in the seasonal spread of that production."

A study of the effects that cutting of top growth has on root and leaf growth in perennial ryegrass and timothy was made by Roberts and Hunt (1936), who claimed that checks to root growth following top cutting were due to removal of stored reserves from roots to tops, especially at flowering, and that perennial ryegrass has its main storage reserves in the root system. They suggested that this may explain why perennial ryegrass stands more defoliation than timothy, where reserves are largely stored in the bases of stems. Jacques and Edmond (1952) studied the effect of various treatments upon top growth yields of perennial ryegrass and cocksfoot, and found that the yield was greater from (a) fortnightly cutting than weekly cutting, (b) 2-inch height of cutting than 1-inch or ½-inch heights, and (c) non-root-pruning than root-pruning. The effect upon yield from root pruning was greater than from height of cutting, which in turn was greater than the effect from frequency of cutting. These workers also found that, in general, the more lenient top treatments were associated with earlier spring growth and with better growth on into the summer. From a study of the effects of clipping upon plants of cocksfoot, bromegrass, ladino clover and alfalfa, Wagner (1952) concluded that damage to top and root growth, and to tiller, rhizome, stolon and leaf development, from grazing or clipping, could be more severe in older plants than in seedlings. The top:root ratio is a direct expression of the amount of top growth that a given root quantity must supply with water and nutrients, so that plants with a lower ratio would be better able to withstand adverse conditions than those with a higher ratio.

B. Seasonal Root Growth

An attempt to relate the seasonal root development of 5-year-old stands of Poa pratensis and Agrostis vulgaris to soil conditions in New Jersey, was reported by Sprague (1933). He found that the maximum root weight in both species was about twice as great as the quantity present at the start of the season, and concluded that at least one-half of the root system is newly generated each spring. Following the period of maximum root weights, a decrease occurred in both species at the time of heavy top growth; while in Poa pratensis, there was a gradual recovery in root weight as top growth became less abundant. Stoddart (1935) used a root banding technique to study longevity in individual roots of 5 range grass species, subjected to a wide range of soil temperatures and moisture levels. In each case, banded roots lived for at least one year, and many were still alive when observations ceased after two years. Some new roots were produced each season.

Using both perennial ryegrass and timothy, Roberts and Hunt (1936) showed that root weight increased in spring and summer, and that maximum root length was attained some time before maximum root weight was reached. During flowering in perennial ryegrass, shoot formation apparently took place at the expense of the roots, since root weight decreased during this period. Stuckey (1941) used mitosis as the criterion of root growth, and found that root tip cells were dividing actively at temperatures close to 32°F, while cessation of root growth during the summer months coincided with periods of high soil temperatures. Over 2 years, she observed that in unclipped timothy, meadow fescue, Poa trivialis, perennial ryegrass, Agrostis vulgaris, and redtop, the whole root system was regenerated annually, new growth commencing in autumn and increasing rapidly in spring. Most of the old roots disintegrated shortly after the new ones developed. With Poa pratensis, cocksfoot, Poa compressa and Agropyron cristatum, only a few new roots were formed after the first spring, and only a small percentage of roots disintegrated. Stuckey's conclusions about Poa pratensis and Agrostis vulgaris, based on evidence of cell division, are not in agreement with those of Sprague in the same species, based on root weight.

In a study of the effect of fertilizer placement on the yield of roots and herbage, Jacques (1943) found two periods during his sampling times when root weights decreased in perennial ryegrass. The first during June and July was of small dimensions and the cause was not determined. The second period followed a rapid increase in root weight lasting until the end of November, and continued to the end of February. This loss in weight was due to the death of some of the earliest-formed roots, and to the loss of cortical tissue from the older part of the roots. Weaver and Zink (1946) used a root banding technique on 3,424 roots on 181 plants of 10 range grass species, over a 3-year period. Root condition was determined by visual examination, living roots having a yellowish-white or brownish colour with good tensile strength. In all species, there was a high rate of root survival over at least the first 12 months, while even at the end of 3 years, many of the banded roots were still in good condition.

The effects of defoliation and root-pruning in cocksfoot and perennial ryegrass was studied by Edmond (1949), who found that the maximum production of herbage and new roots did not coincide. Following planting in March, root initiation was at its lowest in early June as herbage production was falling, but root numbers increased from June as herbage continued to decline. Maximum root initiation was reached in October at a time when a decided increase in herbage growth was becoming apparent. Root numbers then fell away sharply until the lowest point was reached in December. There was a slight recovery of root numbers in January, as herbage growth declined. Seasonal fluctuations were greater in perennial ryegrass than in cocksfoot.

Evidence on the physiological behaviour of the biennial rooting red clover and the short-lived perennial mammoth red clover, was sought by Smith (1950). Carbohydrate root reserves were diminished during winter dormancy, and both carbohydrate and nitrogen root reserves were reduced by early spring growth as well as by new top growth after each cutting. Restoration of root reserves occurred whenever the photo-synthetic area was sufficient to allow storage. The possession of a taproot by legumes should make the storage and movement of reserve metabolites a more prominent feature of plant growth than it is in the monocotyledonous grasses. Troughton (1951) examined the seasonal root development in permanent pastures containing perennial ryegrass, Poa trivialis and Agrostis spp., with smaller amounts of timothy, Yorkshire fog and white clover, in three heavy clay fields at Aberystwith. The amount of root material was lowest in November with a consistent increase until May or June, followed by a gradual decrease, partly due to root death and decay, from July to November. This general trend was modified in one field where there was a decrease from December to February while the pasture was under heavy grazing; while in a second field, a decrease in root weight from May to June was thought to be due to heavy calls on root reserves as the pasture was closed for hay and came into flower.

C. Tetrazolium Staining of Plant Tissues.

There is a steadily growing literature on the use of tetrazolium salts as indicators of reduction-oxidation potentials in biological material. Its major use has so far been as a rapid indicator of seed germination capacity, and nearly all the papers examined dealt either with the application of the compound to seed germination problems, or with the chemistry of the reactions involved. Very little information is available yet from studies made on other plant tissues.

The reduction of 2, 3, 5 - triphenyl tetrazolium chloride at the sites of plant meristematic tissue was examined by Roberts (1951), with the conclusion that the lack of specificity for this reaction makes it probable that no one reductase system is responsible for the reduction of the salt by plant tissues. She says: "It seems more likely that a general redox potential level, maintained by the operation of several physiologically active systems, brings about the reduction of tetrazolium." In an earlier paper, Roberts (1950) pointed out that tetrazolium differed from the majority of redox indicators since it forms an insoluble formazan in its reduced state, and the reaction is therefore irreversible; it is visible in minute quantities so that the reaction is very sensitive; it readily penetrates plant tissues and is not adsorbed; nor does it diffuse from the site of its precipitation. Microscopic sections of fresh material were used for staining, while weak or sluggish reactions were improved by putting the sections into a dessicator attached to a vacuum pump to aid penetration of the tissues by the test solution. The freezing microtome was unsuitable, since the characteristic reduction was either greatly changed or completely absent after freezing.

Actively growing root tips in all the plant species (Allium cepa, Capsicum annuum, Cucurbita maxima, Phaseolus vulgaris, Raphanus sativus, Ricinus communis, and Vicia sativa) examined by Roberts (1950) showed some degree of reducing activity. The strongest reduction was in the zone of cell division, with continuing reduction of progressively less intensity from the apex back, in the outermost and innermost regions of the cortex. Reduction by the pericycle at the sites of secondary root origin, but before there was any histological evidence of secondary root initiation, was also observed in the monocotyledon, Zea mays. Such reduction patterns offer a means of determining physiological differentiation which may exist within tissues, by detecting regions of high metabolic activity.

The influence of tetrazolium salts upon the growth and cytology of onion root tips was studied by Sonnenblick et al (1950). Reduction of 2, 3, 5 - triphenyl tetrazolium chloride occurred in excised root tips, but the effect was not so specific as from the newer tetrazolium salts that were also examined. With the chloride, the entire root is coloured pink to red with the meristem staining deeply, and formazan began to diffuse out of the cells some one to two hours after the start of a test. Ordinary dehydration and clearing procedures with microscopic sections resulted in the loss of most of the precipitated granules.

As a result of a study of tetrazolium staining patterns in pea seedlings, Stafford (1951) suggested that selective adsorption by certain tissues may be involved in the apparent localization of reduced tetrazolium salts. A major source of error in enzymatic cytochemistry is due to diffusion of the coloured indicator compounds after their formation to other sites with a high selective affinity for them. Dyar (1953), using rapidly-acting, light-stable "blue tetrazolium" in a study of the Hill photo-chemical reaction in green plant tissues, claimed that it is improbable that an appreciable amount of such an insoluble compound as reduced "blue tetrazolium" could diffuse from the site of its formation to localized regions within the matter of minutes involved in the reaction. This argument would not apply to the earlier-known tetrazolium salts, such as 2, 3, 5 - triphenyl tetrazolium chloride, because the speed of the reaction is so much slower,

SECTION III

MATERIALS AND METHODS

This section will be presented in three parts:

(a) a description of the planning; the layout, and the establishment of the experimental area,

(b) a description of the measurement methods employed with the top growth, and

(c) a description of the methods used in the examination of the plants' root systems.

A. Layout and Establishment

Four species were used in this experiment.

Perennial ryegrass (Lolium perenne) and Italian ryegrass (L. multiflorum) were selected as being long- and short-lived members of an economically important grass genus in this country. Information on the relative leaf yields of these two species, based on trials carried out at Palmerston North, has been published by Corkill (1950), who showed that in the first 18 months after autumn sowing, perennial ryegrass produces the higher leaf yield during summer and autumn, but that Italian ryegrass is growing more leaf during winter and spring. No data has been reported on the seasonal behaviour of the root systems in these, or other, species in New Zealand. The only explanation, based on experimental evidence for the difference in longevity between these two ryegrass species has been advanced by Cooper and Saeed (1949), who suggested that the behaviour of annual and perennial strains can be explained as a balance between rapid differentiation and elongation of the flowering shoot with inhibition of axillary buds in the annuals, and profuse development of axillary buds as vegetative tillers with slow differentiation of the inflorescence in the perennials. Perennial and Italian ryegrasses therefore seemed to offer good material for a study of root growth over the year, to show its relationship to leaf growth over the same period, and to examine any possibility that longevity may be influenced by the plant's root system.

Tall fescue (Festuca arundinacea) was also selected for inclusion in this experiment, since individual tall fescue plants appear to be very persistent in the field. Annual meadow grass, (Poa annua), was also chosen, since this species has an ephemeral life cycle. It was hoped that tall fescue and Poa annua might represent the more extreme characters involved in longevity, and so serve to highlight the differences in root behaviour which were expected between perennial and

Italian ryegrasses.

Since the plants would need to be examined in their entirety so that the necessary data on root behaviour could be collected, some form of container was required. For this purpose, 134 glazed pipes, each twelve inches in diameter and twelve inches in depth, were available. These pipes had been used successfully in earlier root studies at this College, when it was found that the glazed surface markedly reduced the tendency for roots to aggregate at the sides (Jacques, 1941). With this limited number of pipes, it became essential to have some measure of the variation likely to be found in the material used, so that a layout could be planned which allowed sufficiently frequent liftings over the desired period, yet provided enough plants at each lifting for statistical examination of the results to be carried out with a good chance of establishing significant differences.

The only satisfactory figures which could be found for this purpose had been presented by Edmond (1949). From his figures for numbers of roots per certified perennial ryegrass plant, non-root-pruned and with top growth cut to 2 inches in length every fortnight, it was calculated that the coefficient of variation over 15 plants was 25.70%. On the assumption that all the species to be used in the present experiment would show differences of the same order of magnitude, eight plants of each species should allow a detection power in the statistical analysis of approximately 25% of the mean of the measurements for all plants of all species, taken at any lifting. Edmond's data had been collected from clonal plants whereas the present experiment employed seedlings, but the possibility of greater variation due to this cause was ignored.

Eight replications is considerably below the number of 15 employed by Edmond (1949) or the 32 employed by Yates (1950), in comparable root studies at this College. Both these workers, however, grew plants in an open plot, so that the limit to the number of replications was set by the amount of material that could be handled conveniently by one person. In the present experiment, where the number of pipes was limited, any increase in the number of replications, i.e. in the number of plants of each species at each lifting, entailed a reduction in the number of liftings. This, in turn, imposed either a shorter time over which liftings could be made, or a longer period between successive liftings. Neither Edmond nor Yates found that the efficiency of their statistical analysis was impaired by the lack of sufficient replications, and Edmond concluded that 7 or 8 replications would have been adequate for testing the major effects in his experiment. Since it was anticipated that the differences in root behaviour under study in this trial were quite substantial, it appeared that the number of replications could safely be reduced. For these reasons, 8 replications of each species at each lifting was accepted as a suitable number.

It was thought that the soil volume in each pipe should be sufficient to support four plants, without competition effects becoming severe enough to interfere with growth. Two pipes would thus be required for each species at each lifting, giving a total of 8 pipes in each lifting block, and allowing 17 blocks to be laid down. The shortage of two pipes in the total number needed for such a layout was adjusted by the omission of Poa annua from the final lifting block.

The area chosen for the experiment was a small fenced-off plot of 50 feet by 30 feet, in paddock 4 on the Massey College dairy farm. This plot had been used previously for other studies of root development and had the advantages of being level, open to the sun, and yet sheltered to a considerable extent from wind by nearby hedges and trees, while the sandy nature of the soil allowed free drainage and proved excellent for the easy and clean separation of root systems. A mechanical analysis of the soil was carried out in the laboratory, and the results are shown in Table 1.

TABLE 1. Mechanical analysis of soil on plot area.

The percentages recorded are the average of triplicate determinations made on an air-dried composite sample from 0 - 12 inches depth.

Moisture	1.44%
Loss on ignition	3.53
Clay	10.40
Silt	11.25
Fine sand	34.56
Coarse sand	30.01
	91.19%

During late July and early August, 1952, the ground was cleared, and the pipes sunk into the soil so that the sides were vertical and the top rim half an inch above ground level. The soil removed from each hole was carried to one end of the plot, and then mixed together by turning the heap three times with a spade, as a preparation for its use in filling the pipes. On August 7th and 8th, all pipes were filled with this soil, and heavy rain immediately afterwards (0.34" was recorded at the Grasslands Division meteorological station approximately 300 yards away) helped to consolidate this filling. On August 12th, all pipes were uniformly topped up with soil to within half-an-inch of the top, labelled, and manured. The fertilizer used was a mixture of 2 parts superphosphate: 1 part bonedust: 1 part dried blood, applied at the rate of 12 grams per pipe, which is equivalent to a dressing of 13 cwt. per acre. This fertilizer mixture was sprinkled evenly over the surface and then mixed into the top layer of soil. No further fertilizer applications were made at any stage of the experiment.

The final layout is shown in figure 1. Block numbers were allotted from the table of random numbers given by Snedecor (1946), while the species were allotted to pipes within each block from the table of random permutations of 9 numbers given by Cochran and Cox

FIGURE 1.

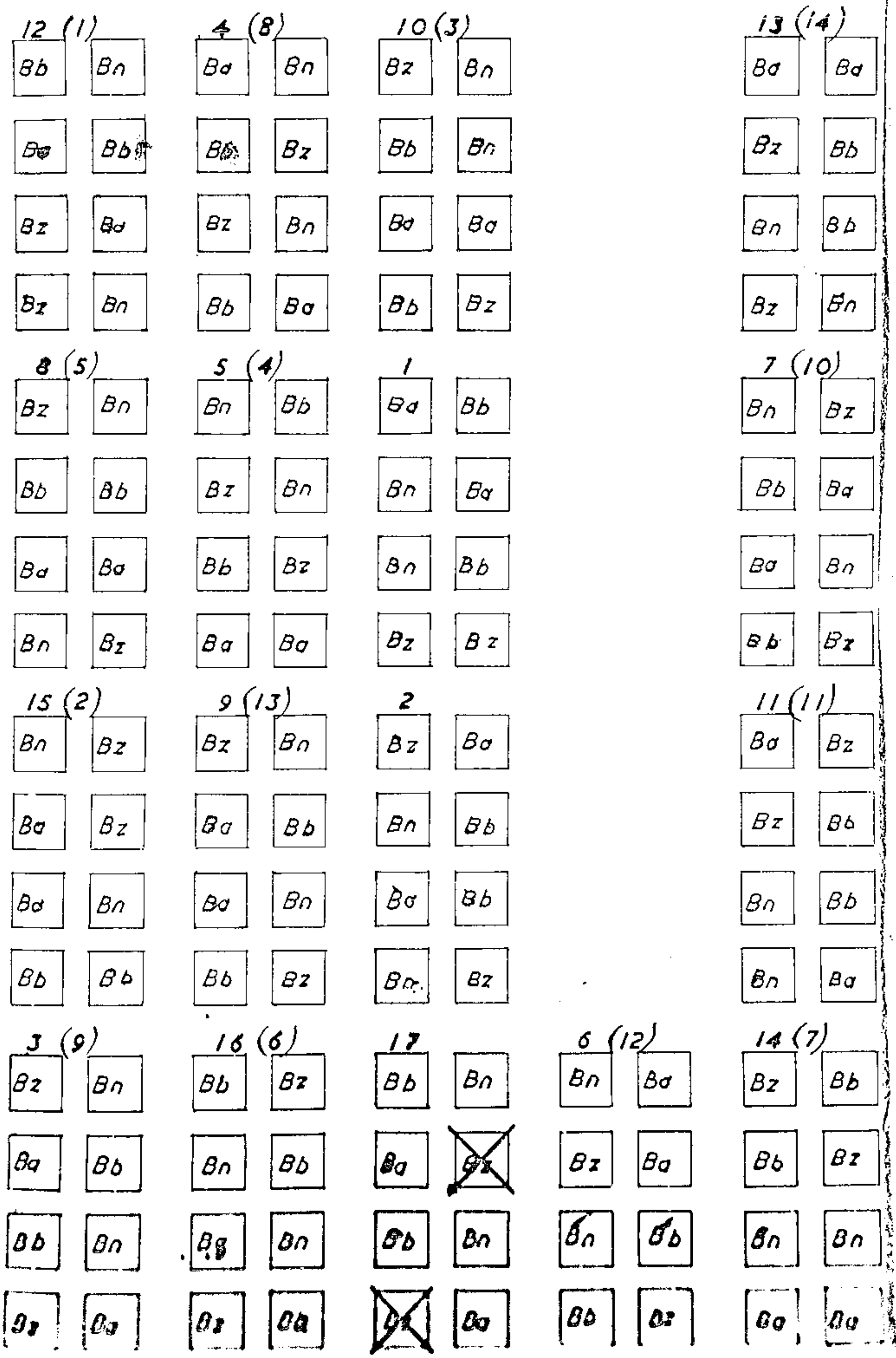
Experimental Layout.

Each square represents one pipe; the species grown in each pipe are given by the following key :-

Ba = perennial ryegrass
Bb = Italian ryegrass
Bn = tall fescue
Bz = Poa annua

The pipes were arranged in blocks of eight. The lifting sequence for each block is given by the numeral (1 to 17) on the top of each block. The number in brackets is the lifting sequence for the two Poa annua pipes in the sub-trial with this species.

EXPERIMENTAL LAYOUT.



(1950). Pipes within a block were separated by a distance of two feet between their centres, while the distance between the centres of pipes in adjoining blocks was three feet. These spacings allowed easy recognition of the blocks, and facilitated both movement around the area, and control of weeds between the pipes. The strip below block 6 was not used, as a small pit had been dug here earlier and there appeared to be some risk of subsidence of the surface soil, which would have affected the setting of the pipes.

The plant material used came from various sources. Nucleus Stock seed of both perennial (Ba 40, 1950/51) and Italian ryegrass (B6408, 1951/52) was supplied by Grasslands Division, and while not genetically uniform, should have been capable of growing into vigorous plants without any marked heterogeneity of type. While the use of clonal material from one plant provides tillers of uniform genetic constitution, the individual tillers will vary to some extent in vigour and size, and it may be difficult to separate sufficient comparable tillers from the one parent plant for the complete experimental planting. Seedlings are easier to prepare and handle, and selection of similar seedlings for planting out by discarding unduly strong or weak ones, can help in the attainment of reasonable uniformity. Yates (1950) successfully used Nucleus Stock seed of perennial ryegrass in a comparable experiment.

The Poa annua seed used was taken from seed samples of various species received at the Seed Testing Station, Palmerston North, for analysis, in some of which it was a common impurity. The tall fescue seed was collected by hand from an isolated group of plants growing in a drain enclosure behind Wharerata, Massey College. In the case of both these species, the seed could include much variation in plant type, but here again this was reduced to some extent by the use of only comparably sized seedlings at planting out.

Seed boxes for each of the four species were prepared and sown on 16th July, 1952. The boxes were kept in a warm glasshouse until the young seedlings were about half-an-inch in height, when the boxes were transferred to a cold frame outside for hardening.

Planting out was done on the 13th, 14th and 15th August, 1952. The leaves of each selected seedling as it was planted were cut back to a length of one inch, to impose uniformity and to reduce moisture loss by transpiration. A hole four inches deep was made with a dibble for each plant, and the roots were placed so that they reached to this full depth. The hole was then filled with soil which had been passed through a fine sieve. The holes were spaced so that each one was approximately equidistant from its neighbours and from the sides of the pipe. As each pipe was planted with its four seedlings, it was watered until the surface layer was saturated. This technique was successful as all plants struck, and no replacement planting was necessary within any species.

Further watering by hand was done on four occasions during the six weeks after planting - on 26th August, and 11th, 23rd and 30th September respectively. The weather was fairly dry over this period, and the watering became necessary, to prevent checks to the growth of the establishing seedlings. From October onwards, further watering was not required, and the plants at no time showed evidence of lack of moisture. Rainfall and dew provided adequate moisture supplies.

An analysis of rainfall, evaporation from a free water surface, minimum grass temperature, soil temperatures measured at 4-inch and 12-inch depths, and the number of sunshine hours, for weekly intervals over the experimental period, as prepared from the records of the Grasslands Division meteorological station, is presented in Appendix 3. The total rainfall, the number of days on which rain fell, and the number of sunshine hours over the experimental period, together with the average figures for the equivalent period taken from Grasslands Division's records since observations began in 1928, are set out in Table 2.

TABLE 2. Rainfall and sunshine figures for experimental period, and the 25-year average.

	Actual figure for period: 17/9/52 - 16/11/53	Average figure, 1928-54 for period 17 Sept. to 16 Nov. of following year.
Rainfall	55.38 inches	45.42 inches
Number of rain days	227	201.6
Sunshine hours	1792.6	2117

The actual period of the experiment thus received nearly 10 inches, or approximately 22% more rain on 26 more days, than the average for the comparable period calculated over 25 years, while the number of hours of sunshine was reduced by 324, or approximately 15%.

At all stages of the experiment, the pipes were maintained free of weeds, while the paths and areas between the pipes were periodically hoed to remove weed and grass growth.

B. Top Growth Measurements.

It appeared that some measure of the leaf growth of the plant material used in this experiment would be necessary in any assessment of the differences in root behaviour between the species. While the general leaf growth pattern of the two ryegrass species was known from Grasslands Division's published results, these provided no answer to the leaf yields that would be obtained under the conditions of this experiment, on the sandy soil type, and in this particular season which proved to be wetter and duller than usual. Further, no leaf growth data were available for either tall fescue or Poa annua. Actual measurements would therefore have to be taken on all four species.

Since this information was only incidental to the main study of the root systems, it was decided that the time and labour involved in cutting, drying and weighing each plant, or even each block, separately, so that a complete statistical analysis could be made of leaf growth, was not justified. The method adopted was to take the yields in duplicate samples, eight blocks (numbers 3, 15, 8, 12, 16, 9, 5, 4) giving sample A and nine blocks (numbers 17, 2, 1, 11, 6, 10, 7, 13, 14) giving sample B. The blocks in each sample remained there during the whole experiment, so that as each block was lifted and the plants removed, the number of plants of each species included in the appropriate sample was reduced by eight. It is likely, therefore, that as the number of plants cut became small towards the end of the trial, errors would increase. The use of the duplicate samples A and B should give some idea of this, and also served the purpose of checking the yields against gross errors.

The cutting technique adopted was to cut with scissors at a length of two inches, all leaves being lifted vertically in the hand before the cut was made. That is, all leaves were cut to a length of two inches, rather than the plant being cut to a height of two inches with straggling leaves remaining much longer or even not being cut at all.

The length of two inches was constantly checked with a ruler over the first three cuttings, after which eye appraisal of the length was made. Occasional check measurements of the length were made during the experimental period, but no marked deviation from the two inch length was ever noted.

The frequency of cutting was varied over the trial period. The first cut was taken on 17th September, 1952, at which stage all plants had established and were making obvious growth. From then on until the 16th April, 1953, plants were cut at fortnightly intervals, although it was not possible to adhere strictly to a fourteen day schedule. Rain was the main cause of the variations of one or two days which were sometimes necessary. By mid-April, leaf yields had decreased markedly as temperatures were falling during late autumn, and to avoid the possibility of undue interference with root behaviour at a time when top growth was relatively slow, the periods between cuts were increased to three weeks. Again, variations of up to four days were sometimes necessary with this planned cutting interval of twenty-one days. This interval was thereafter maintained until the completion of the experiment, which appeared to coincide with the spring growth flush as judged from general pasture growth.

The two-inch length of cutting, and the fortnightly frequency of cutting, represented the most lenient treatment employed by Edmond (1949), and was satisfactory in that there was no evidence of checks to either top growth or root growth and initiation imposed by the treatment being over-severe. The use in this experiment of the same cutting treatment employed by Edmond had the further advantage that direct use of the results could be made to confirm, or otherwise, certain observations made by this worker. It is considered that the change to the three-weekly cutting period during the slower leaf growth of winter is not likely to have had effects on the plant great enough to invalidate the top growth results in this experiment, and there is no evidence in the results that such treatment had any measurable effect on root behaviour.

It was found at the cut on 13th November, that some of the perennial ryegrass plants had emerging flower-heads, and these also appeared in some tall fescue plants for the first time on 11th December, and in some Italian ryegrass plants on 22nd December. From these dates onwards, at each cutting date, a record of the individual plants showing emerging flower-heads was kept for each species until the last appearance of heads on 20th May, 1953, in tall fescue. An analysis and discussion of these observations is presented in Appendix 4. The importance of these flower-heads for the present purpose is that they are stem tissue included with the leaf tissue in the weights of top growth, for the periods during which they occurred. No attempt was made to separate them from the leaves. The cutting length of two inches was long enough to avoid the inclusion of basal stem tissue with the leaves, so that top growth weights for the periods when flower-heads were not being formed, are pure leaf tissues. The duration of flowering in the three species, and hence the periods during which flowering stem tissue is included with leaf tissue in the top growth yields, are as follows:

Perennial ryegrass: 13th November, 1952 to 18th February, 1953.
Italian ryegrass : 22nd December, 1952 to 18th February, 1953.
Tall fescue : 11th December, 1952 to 20th May, 1953.

It should be noted that at the commencement and particularly near the end of these periods, few plants were recorded with flowerheads. In the three species, the periods during which at least 25% of the plants were flowering, and hence during which an appreciable amount of flowering tissue is included with the true leaf tissue, are:

Perennial ryegrass: 28th November, 1952 to 21st January, 1953.
Italian ryegrass : 6th January, 1953 to 21st January, 1953.
Tall fescue : 11th December, 1952 to 4th February, 1953.

In addition, more than 10% of the tall fescue plants were recorded as flowering from the cut on 18th February through until 4th May, 1953.

The leaves, immediately after cutting, were placed in preserving jars with airtight seals, and taken to the laboratory. The total green weight of herbage for both samples in each species was measured, and then from each sample, 2 lots each of approximately 100 grams were taken at random and weighed in metal trays. These trays were dried in a Hearson oven at 100°C for 24 hours, before removal to a dessicator for cooling and re-weighing. In a few cases, checks were made to determine whether any further loss of moisture occurred on re-drying, but in no case was any further loss in weight recorded. The dry matter percentage of the herbage in each tray was calculated from these figures, the duplicate determinations for each sample again serving as a check against gross errors. By summing the green weights and the dry weights of the herbage in the four trays of each species, the dry matter percentage for the top growth of each species at each lifting was calculated. Finally, the dry weight yield of the herbage was determined by combining the total green weight and this dry matter percentage.

The yield figures used in the section on results, is derived from this dry weight yield. Since the number of plants decreased during the experimental period as blocks were lifted, it became necessary to divide this dry weight yield by the number of plants cut, to give a measure of the dry weight of herbage per plant. Further, it has already been explained that the cutting frequency was altered during the experiment, and the actual cutting intervals were not strictly either 14 or 21 days. A more useful measure of yield is therefore obtained by dividing the dry weight of herbage per plant by the number of days in the cutting interval. This gives the dry weight yield of herbage per plant per day for each cutting interval. This index of top growth is the best that can be derived from the data collected in this experiment, and while certain errors will be present, these are unlikely to seriously affect the comparisons of herbage yield made within and between species.

Dry weights of herbage were used in preference to green weights in the compilation of results. Greenhill (1936,(a) and (b)) has shown that conclusions based on green weight comparisons can be misleading, but that the use of dry weights and dry matter percentages of herbage (and roots) allows legitimate comparisons to be made within and between species at different dates. Such comparisons are, of course, an essential feature of an experiment of this nature.

The method of drying employed is one of three recommended by the N.Z. Institute of Chemistry's Committee for Standardization of Plant Analytical Methods (Melville, 1947) for tissues such as leaves which are relatively low in soluble carbohydrates. The particular method used here was chosen in preference to the alternatives because a suitable oven was readily available. All weighings were made on an E.T.A. Triple Beam Balance, which was satisfactory for the heavy weights involved (sometimes over 1000 grams), and which could be read to an accuracy of 0.1 gram.

Poa annua plants did not long survive the cutting treatment. By the fifth cut on 13th November, 1952, only 36 plants out of the original 128 were showing any signs of growth, and most of the remainder were completely dead with no vestige of green tissue. Flowering had been profuse in all plants from the second cut onwards. It was therefore decided to discard Poa annua from the main trial, and all pipes allotted to this species were cleared of plants. It was further decided to run a sub-trial with Poa annua during 1953, and a fresh supply of seed was obtained from the Seed Testing Station and sown into a seedbox on 3rd June, 1953. Plants were put out into the pipes on 26th June, a fresh allocation of numbers for the lifting sequence being made. The first top cut was taken on the 14th August. The first lifting for root observations was made on the 3rd August as soon as the plants were well established. The next two liftings were made at fortnightly intervals, but from then on, liftings were made weekly until completion of the trial on 16th November, 1953. Details of the layout and the results of this sub-trial are presented in Appendix 5.

C. Root Measurements.

This experiment was planned for observations to be made over a full year. With 17 blocks, this allowed liftings to be made at three-weekly intervals, periods short enough to allow the detection and following of trends in root behaviour as they occurred. That is, liftings of plants at three-weekly intervals should permit a fairly precise delimitation of any significant periods when the root systems of the various species were showing differences.

The first block was taken up on 4th December, 1952, and the second block on 29th December. These two blocks were used primarily to develop techniques, both in actual lifting and washing of the plants, and in laboratory measurement procedure. The third block was lifted on 26th January, 1953, and thereafter, blocks were taken up at twenty-one day intervals during that year, the experiment being finalized with the lifting of block 17 on 16th November, 1953.

At each lifting, a hole was dug alongside each pipe in the appropriate block. The pipes were carefully pulled over so that they lay horizontally, and the soil adhering to the base of each pipe was trimmed off level with the bottom rim. This meant that only $11\frac{1}{2}$ inches depth of soil, with its contained roots, were examined. It was not practicable to get any measure of the amount of root tissue which had penetrated below this depth, but there was never any evidence that the amount was appreciable.

Reported studies on root development confirm that most of the root tissue is confined to the top few inches of soil. Troughton (1951) sampling Brook Field at Aberystwith, found that 79.3% by weight of the root tissue occurred in the top 3 inches of soil, 89.9% in the top 6 inches, and 95.7% in the top 12 inches. This field was carrying a very mixed 10-year-old pasture, under lenient grazing and occasional hay crops. Gist and Smith (1948) on a shallow silt loam soil in West Virginia, examined the root development of several forage grasses.

Their results for two "English" grasses (they did not include rye-grass in their experiment), were as follows:-

TABLE 3 Weight of root tissue in pounds per acre at various depths in a shallow silt loam soil (after Gist and Smith (1948)).

Species	0 - 3 inches	3 - 12 inches	12 - 18 inches
Cocksfoot	1247	252	29
Timothy	680	73	6

Jacques (1941) measured in March, 1939, the air-dry weights of root tissue down to a depth of six feet in a perennial ryegrass - white clover sward under grazing, following sowings in the preceding autumn and spring. He found that from the autumn sowing, 1171 milligrams of root tissue occurred in the first 12 inches of soil, out of 1584 milligrams for the full depth of 6 feet. From the spring sowing, 1210 milligrams were recovered in the top 12 inches, and 1578 milligrams in the full 6 feet sampling depth. In the face of evidence of this nature, it is unlikely that any errors which would affect the results and conclusions from the present experiment were introduced through discarding root tissue below 11½ inches in depth.

After trimming of the base, the pipes were carried to one end of the plot from which there was a fall away down-hill, which proved ideal for the disposal of washing water. A stream of water from a hose was carefully played on to the base of the pipe, and the soil was easily removed by this gentle flow. It took about twenty minutes to wash out each pipe so that a minimum of damage was done to the roots. At the later liftings when the cortex had largely disintegrated from many of the older roots, and they were therefore rather thin and brittle, there was some loss of roots in this process, but examination of the washings showd that the number so affected was very small. In view of the difficulty of obtaining an accurate count of these roots, they were ignored. All species appeared to be affected by this factor to about the same degree.

At certain of the liftings, one or more of the Italian ryegrass plants had died. The remaining plants of this species were treated as described in this section, and allowance was made for the missing plants in the statistical examination of the results, as will be seen later. In no case was any plant of either perennial ryegrass or tall fescue missing, so that the full number of eight was recorded at each lifting for these two species.

The plants, after removal from the pipes, were immediately wrapped in saturated towelling and taken to the laboratory. Here, each set of four plants was subjected to prolonged and gentle washing, during which the root systems were untangled and cleaned from soil as far as practicable. The plants were finally suspended on wires and placed in battery jars full with water so that the whole root system was immersed. They were held here until observations were made, these taking some three or four days to complete.

Up to, and including the twelfth lifting on 3rd August, representative plants of each species were used for tetrazolium staining. The compound used was 2, 3, 5 - triphenyl tetrazolium bromide, prepared by the May and Baker Pharmaceutical Coy., and sold as "Grodex" germination indicator. The selected plants were suspended in narrow 200-millilitre beakers, and a freshly made 1% solution of the tetrazolium salt in distilled water poured in to completely cover the roots. The beakers were placed in an incubator at 30°C for eight hours. On removal from incubation, all plants were immediately examined, and a description made of the gross staining patterns observed in the roots. On several occasions, attempts to cut sections for microscopic study of the staining pattern were unsuccessful and no satisfactory picture of this was obtained. The action of tetrazolium salt is not to stain the actual tissues, but is a precipitation of the red-coloured reduction salt, formazan, at the sites of its formation. The normal techniques for clearing and mounting sections were not suitable, and it was not possible to obtain a clear view of the microscopic sites of the formazan deposition. General indications were, however, that the roots hairs and the stele or vascular cylinder, consistently showed a greater deposition of salt, as judged by the deeper colour, than did the cortical tissue.

This tetrazolium staining technique was discontinued after the lifting on 3rd August, since by that time so much of the root system was discoloured as the older roots became dark brown, that it was no longer possible to recognize the precipitated formazan salt.

Each plant was carefully cut through at the crown with a razor blade. A count was made for each plant of the number of live tillers present, any tiller showing green tissue being counted as alive. Tillers showed much variation in size within each plant and over the course of the experiment, but it was not possible to place tillers consistently in any size groups.

The severed root system from each plant now received a further washing to remove soil carried between the roots in the region of the crown. A count was made of the total number of roots, this operation being greatly aided by careful teasing apart of the individual roots held about an inch below the surface of the water in a large white basin. During the first four liftings, the entire root systems were light in colour, though there was a noticeable tendency to darkening with successive liftings. At the fifth lifting on the 9th March, "white" roots became noticeable because of their colour and these roots could be distinguished in each species at all subsequent liftings. A count was taken of their number for each plant, and they were separated from the remainder of the root system. This separation was easily made as none of the white roots at any stage of the experiment exhibited lateral branching.

During the root counting process, observations were made on certain other root characters, principally colour and the condition of the cortex.

As soon as the count was completed, both "white roots" and "roots other than white" were dried separately on towelling to remove moisture carried on their surfaces, and were then weighed to the nearest milligram on an air-damped Sartorious balance. This gave their fresh weight, equivalent to the "green-weight" of the top growth.

Drying of the root systems was carried out at 100°C for 24 hours in the Hearson oven. Oven-drying was considered necessary, since the resultant weights by virtue of the constant drying conditions, should be comparable both between and within the species for all liftings. This would not have been the case with air-drying of the roots since controlled constant-humidity facilities were not available. A further advantage of oven-drying was that the time and temperature used for the roots was the same as those used with the top growth, so that these two sets of data should be directly comparable. The Committee on Standardization (Melville, 1947) made no recommendations for the drying of storage tissues or for tissues with a high soluble carbohydrate content (such as carrots), but it was thought that grass roots were not likely to have a chemical composition which would be unduly affected by the oven-drying technique employed. This assumption would appear to have been borne out by the results.

A check was made of the efficiency of the root washing technique in the removal of soil adhering to the root systems, by the ignition and determination of the insoluble ash content in representative root systems from plants of the seventh, tenth and seventeenth liftings. After all measurements were completed, these roots were placed in crucibles and ignited in an electric muffle furnace at 800°C for two hours. On cooling, the residue was taken up with excess normal hydrochloric acid and evaporated to dryness. Distilled water was added in excess, to dissolve the soluble components present, and this solution was carefully filtered through Whatman No. 40 papers. After drying, these filter papers were placed in crucibles and ignited at

800°C for two hours in the electric muffle furnace. The crucibles were cooled in a dessicator, and then weighed on the Sartorius balance. Results are given in Table 4.

TABLE 4. Determination of insoluble ash residue after ignition of root systems.

Class of roots	Lifting no.	Perrenial ryegrass: Dry weight of roots, mgm.	Ash Weight mgm.	% ash.	Italian ryegrass: Dry Weight of roots, Mgm.	Ash Weight mgm	% ash	Tall fescue: Dry Weight of roots mgm.	Ash Weight mgm.	% ash
Roots other than white	7	1941	41	2.11	192	1.5	0.78	3222	93	2.89
	10	1409	28	1.99	829	11	1.33	3000	93	3.10
	17	708	16	2.26	981	21	2.14	1996	69	3.46
White roots	7	34	0.5	1.47	45	0.5	1.11	181	2	1.10
	10	223	3	1.35	190	2	1.05	311	4	1.29
	17	39	0.5	1.28	74	1	1.35	176	5	2.84

In addition, duplicate determinations were made on the ash content of unused Whatman No. 40 papers, with negligible results.

Most of the insoluble ash residue weighed above will have been derived from soil adhering to the roots after washing has been completed. The fraction derived from iron, aluminium and similar compounds in the roots themselves, will be negligible. The results show that more ash is derived from the roots other than white, and in the later liftings at least, it is probable that some of this soil may have lodged between the stele and the cortex, as the cortex became loose and commenced sloughing off. The larger root systems also had a greater amount of residual ash than did the smaller root systems (compare the tall fescue roots other than white with the remaining samples). Further, there is a consistent trend for ash contents to increase in the later liftings over the contents for the earlier lifting, with the unexplained exception of perennial ryegrass white roots.

It can be contended that since the greatest percentage of residual ash recorded here is only 3.46%, the amount of soil left attached to the root systems is so small that it would not invalidate conclusions formed about root behaviour on the basis of root dry weights. Equal care was taken with each plant in this experiment to get as complete washing as possible.

Root systems from representative plants at the eleventh, twelfth and sixteenth liftings, were also retained after all measurements had been completed. These roots were later analysed for their crude fibre content by the Biochemistry Department, Massey College. Results of these analyses will be presented in the appropriate section.

SECTION IV

RESULTS.

The results of this experiment will be presented in four sections:

A. An analysis of top growth, based on the dry matter yields and percentages of leaf tissue (plus flowering stem tissue for the appropriate periods) from the cutting treatment, and on the number of live tillers.

B. A description of the nature of the changes which occurred in the root tissues, insofar as changes were observed and measured in the course of this experiment.

C. An analysis of the numbers and the dry weights of white roots and of roots other than white, per plant and per tiller, together with an analysis of the percentage of the total root system classified as white roots, on both a number and a dry weight basis.

D. An analysis within each species of the relationships between the dry weight yield of leafage, and the number and the dry weight of white roots and of roots other than white.

For the sake of convenience in the presentation of the results, certain conventional abbreviations will be used. These abbreviations and their full meaning are as follows:

Ba	=	Perennial ryegrass
Bb	=	Italian ryegrass
Bn	=	Tall fescue
N.S.	=	result not statistically significant.
*	=	result statistically significant at the .05 (or 5%) level.
**	=	result statistically significant at the .01 (or 1%) level.
F	=	the variance ratio, for specified conditions.
$d_{.05}$	=	difference required between two means for that difference to be significant at the

.05 level.

$d_{.01}$ = difference required between two means for that difference to be significant at the .01 level.

Mean = the mean value for specified characters, over eight plants at each lifting in perennial ryegrass and tall fescue, or over the appropriate number of plants in Italian ryegrass.

S.E. = the standard error, or the standard deviation of the mean as defined above.

r = the correlation coefficient between two specified sets of data.

A. Leaf Yields and Tiller Numbers

Information on the top growth made by the experimental plants became available from two sources - the leaf (plus flowering stem) yields and dry matter percentages resulting from the top cutting treatment, and the number of live tillers per plant counted at each lifting date. This section of the results can therefore be divided into four sub-sections, as follows:

a. a description of the dry matter yields and percentages for the leaves (and flowering stems) of each species. (Note; all future references to dry matter yields and percentages will be for "leaves", it being understood that flowering stems are included in this for the respective periods during which they were formed).

b. an analysis of the number of live tillers per plant for each species.

c. a combination of the dry matter yields of leaf, and the number of tillers, to give some measure of the leaf yield per tiller within each species over the experimental period.

d. an analysis of the relationship within each species, between the dry matter yield of leaf and the number of live tillers.

a. Leaf yields and dry matter percentages.

The leaf yields and dry matter percentages obtained for each species at each of the top cutting dates are set out in tabular form in Appendix 1, and in graphical form in figures 2, 3 and 4 for perennial ryegrass, Italian ryegrass and tall fescue respectively.

In the case of perennial ryegrass, there was a steady increase in leaf yield from September when the cutting treatments commenced, to the middle of November, when the yield reached 90 milligrams of dry tissue per plant per day. The decline in yield to 70 milligrams shown for the top cut on 28th November, is an anomaly which appears in both the other species as well, though in tall fescue, the growth is so vigorous that the check which was operating at this stage did not produce an actual decrease in yield. Reference to the weather data in Appendix 3, shows that for the week ending on 25th November, grass minimum temperatures were reduced by 42°F, and the 4 inch soil temperature by 2.3°F from the preceding week. It is likely that at least part of this depression in leaf yield was due to this temperature difference. During December, growth recovered, and the peak of 97 milligrams of dry leaf tissue per plant per day was reached at the end of December. The leaf yield remained above 90 milligrams until the end of January and above 80 milligrams during February, but in March there was a rapid decline in growth so that the yield fell to 50 milligrams per plant per day. From April through to the second half of July, the leaf yield declined steadily to 17 milligrams, with the exception of an increase in yield at the top cut on 4th May, which also appeared in the other two species. This increase in leaf yield can also be at least partly explained by reference to the temperature data in Appendix 3, where it is shown that the grass minimum temperature for the week ending 28th April was 3.0°F, and the 4-inch soil temperature was 2.0°F above those temperatures for the preceding week, and that this temperature rise was also apparent, though to a lesser

FIGURES 2, 3, 4.

The dry weights of herbage per plant per day; the dry matter percentages of the herbage; and the number of live tillers per plant, in perennial ryegrass, Italian ryegrass, and tall fescue respectively.

FIGURE 2. PERENNIAL RYEGRASS.

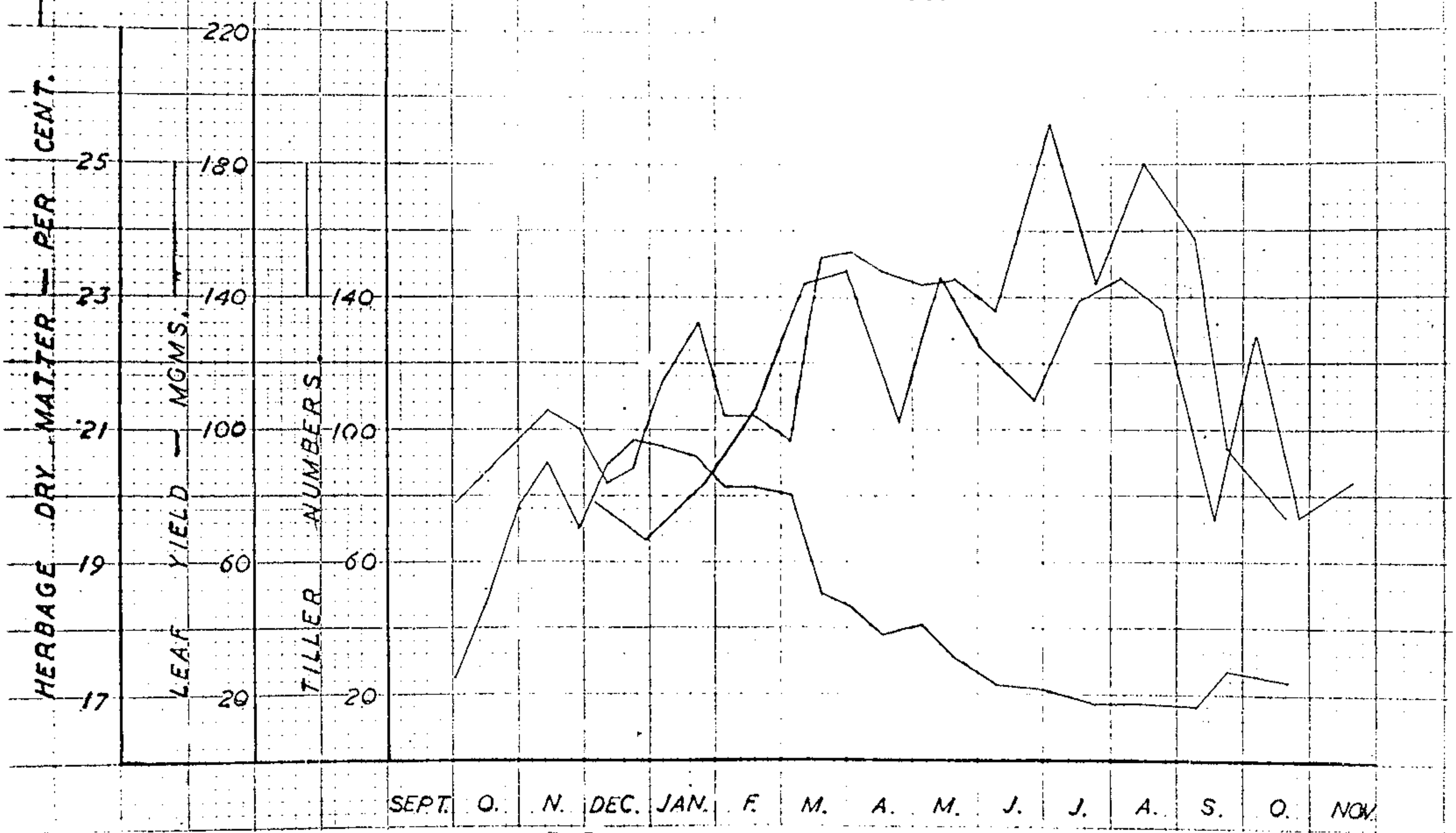


FIGURE 3. ITALIAN RYEGRASS.

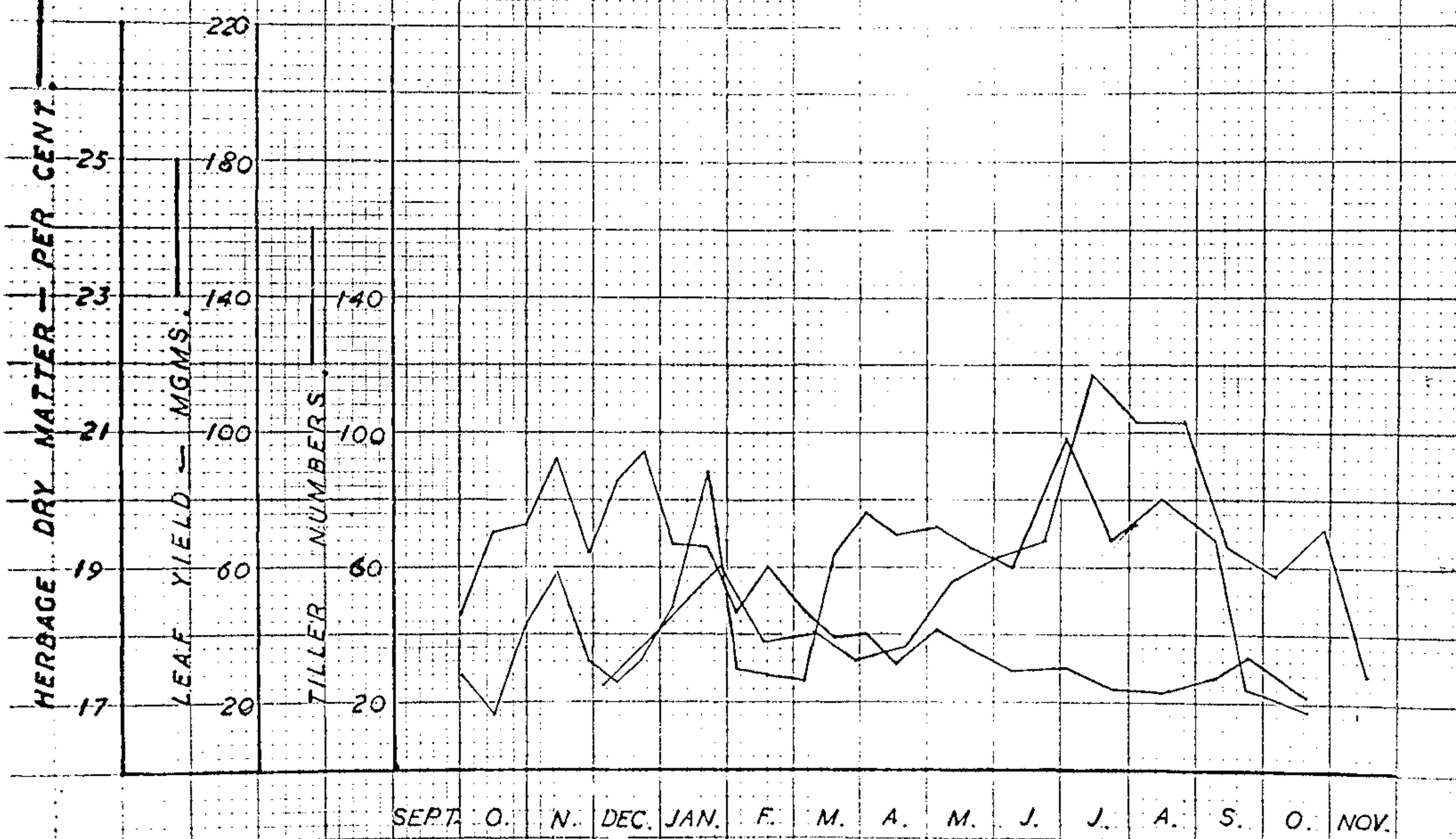
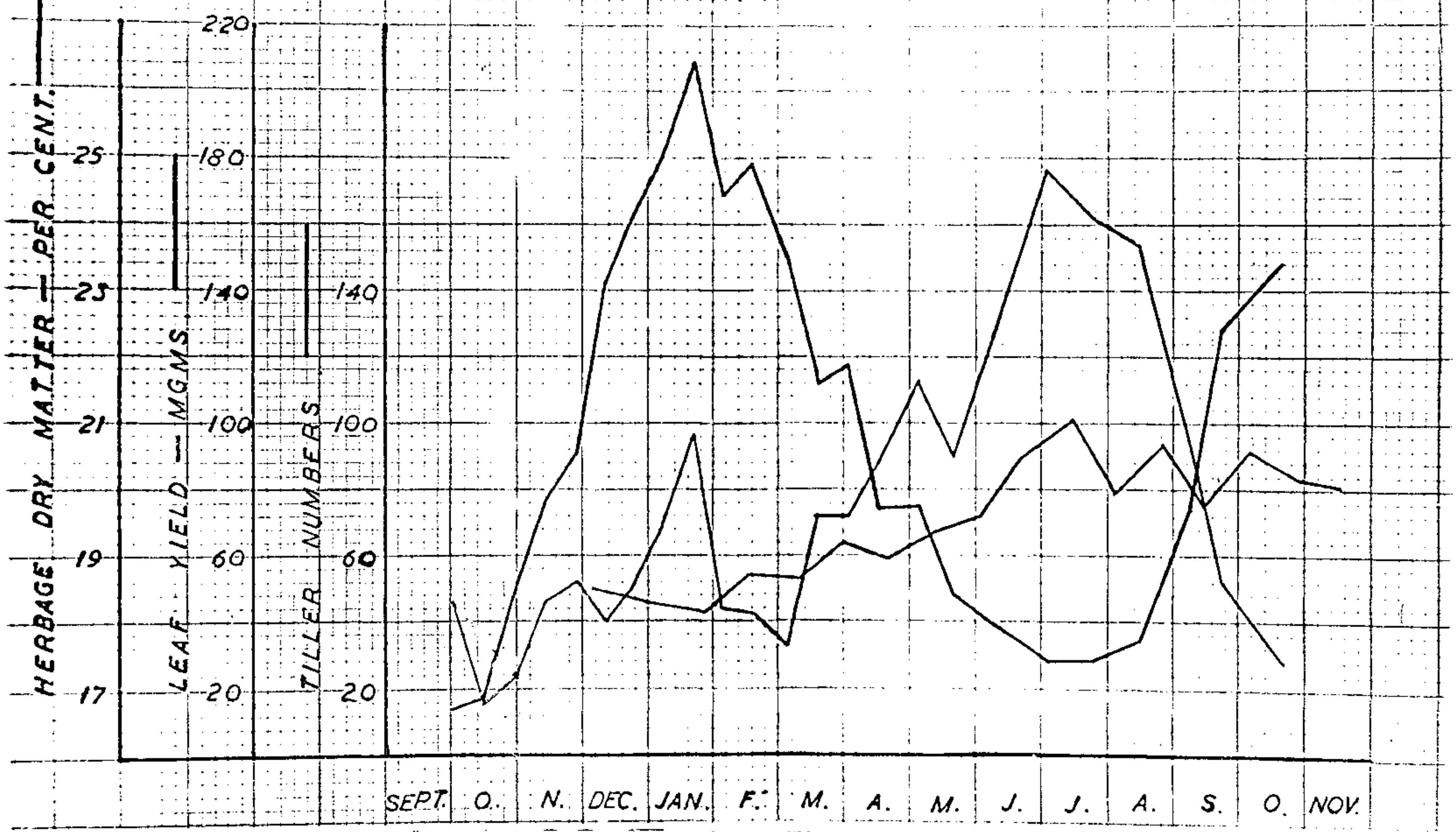


FIGURE 4. TALL FESCUE.



extent, in the week ending 5th May. Leaf yield remained at this level of 17 milligrams of dry tissue per plant per day until early in September, when an increase in leaf yield became evident to 27 milligrams per plant per day. The reduction in leaf yield found at the final cut on 19th October can be explained on the grounds that only 16 plants were involved in this cut, and reference to the tiller and root numbers for the plants in the final two root liftings show that these plants were smaller than average.

The dry matter percentage in the top growth of perennial ryegrass shows a fairly inverse relationship to the dry matter yield of leaf. During October while the plants were establishing and growing vigorously, the dry matter percentage is below 20%, and from early November through until early March, during the period when leaf yield reached and maintained its maximum level, the dry matter percentage was between 20% and 22%. The one exception to this was the cut on the 21st January, when in all three species, there was an unexplained increase in the dry matter percentage. During March, the dry matter percentage increased to over 23%, and remained at this level until late in June. At the cut on 2nd July, the dry matter percentage had increased still further to 25.6%, and during the next period while leaf yield was at its lowest level, the dry matter percentage fluctuated on either side of the 24% mark. During September, when leaf yield increased, the dry matter percentage dropped suddenly to 20.7% and still further to 19.7% at the final cut on 19th October, indicating that the plants in the final lifting blocks, though small, were growing vigorously at this stage.

Italian ryegrass plants were making more growth during the establishment period up until the middle of October than were the other species, but reached a peak value at 92 milligrams of dry leaf tissue per plant per day on the cut of 13th November, at the same time as perennial ryegrass. After the decline during late November discussed earlier, yield recovered to the maximum value of 94 milligrams on the

22nd December, but this leaf yield was not maintained. It had dropped by the 6th January to 67 milligrams, and then declined steadily, with one unexplained anomalous low yield on 4th February, and a second low yield on 16th April which has already been discussed, to 29 milligrams by early June. From June until the middle of August, the leaf yield remained between 20 and 30 milligrams per plant per day, and then increased from the second part of August. The final cutting taken on 19th October also showed a marked decline in yield, but here again the plants which remained in the final two root lifting blocks were much smaller than average.

The dry matter percentage of the Italian ryegrass herbage was approximately 17% during the initial vigorous growth period, and then fluctuated, with the exception of the unexplained increase on 21st January, between 17% and 19% until the middle of March. With this species, there was no clearly marked increase in the dry matter percentage during the period when leaf growth was receding from its maximum value after the 22nd December. During March, there was a sudden increase in the dry matter percentage of the herbage to 19.2%, and the figure then remained between 19% and 20% until early in September, with the exception of a 20.9% result on 2nd July. The dry matter percentage dropped back to 17% by late September, which shows that in this species also, the plants which remained in the final two root lifting blocks were actively growing although they were small in size.

Tall fescue was the last of the three species to commence appreciable growth, but from the middle of October, the leaf yield increased steadily and spectacularly to reach a maximum level of 208 milligrams of dry leaf tissue per plant per day at the cutting on 21st January. This peak was not maintained, but declined fairly steadily to 48 milligrams by 20th May. From that date, leaf yield passed through a pronounced and regular trough, the minimum values of 26 milligrams being reached on the two cutting dates in July. Thereafter, tall fescue became the earliest of the three species to commence growth in the spring, and the leaf yield increased rapidly from the middle of August, to reach a value of 148 milligrams of dry leaf tissue per plant per day at the last cut on 19th October.

In tall fescue, the dry matter percentage of the herbage was at first 17%, but fluctuated about 18% from early November through until the middle of March (the value of 20.8% on 21st January was an unexplained anomaly in common with the other species at this date), which covered the period while growth was increasing to its peak and the initial part of the decline. After the middle of March, the dry matter percentage increased fairly regularly to a maximum of 24.8% by the 2nd July, when the leaf yield was at its minimum. The dry matter percentage remained at approximately 24% until the middle of August, after which there was a steady decrease to a value of 17.4% by the 19th October. This decline corresponded to the rapid increase in yield of leafage over the same period.

A comparison of the leaf yield data for the three species brings out two major points for consideration at this stage. Firstly is the spectacular yield given by tall fescue under the conditions of this experiment. The establishment period of this species appeared to be longer than for the ryegrasses, and its growth run in the first spring did not commence until the latter half of October. In the second spring, its growth commenced a month earlier than the ryegrasses, after the middle of August. While tall fescue can have certain harmful effects on livestock grazing it, and frequently becomes a weed in paddocks where its control is neglected, the growth performance it has given in this experiment, together with the fact that it showed a shorter winter growth trough than the ryegrasses, is impressive. It could be a satisfactory species for the study of growth patterns under controlled environmental conditions. Secondly the yields given by the two ryegrass species under the conditions of this experiment follow the reported growth data published by Corkill (1950). Italian ryegrass was the first species to make appreciable growth after establishment, but reached its peak yield during late November and December at the same period as perennial ryegrass. The fall in yield from this peak was much more rapid in Italian ryegrass than in perennial ryegrass, so that over the period of late summer and autumn from the beginning of the year until late April, perennial ryegrass outyielded the Italian ryegrass. At the beginning of May, the yield of Italian ryegrass became greater than the yield of perennial ryegrass, and this held at a level of between 6 and 10 milligrams of dry leaf tissue per plant per day through the winter period and into the spring until the cutting treatment was completed. These results are therefore in accordance with the recognized growth cycles of these two ryegrasses.

A comparison of the dry matter percentages of the leaves in all three species also brings out two points for notice. Firstly, there is a general inverse relationship between yield and dry matter percentage, in that the percentage is lowest when the plant is actively growing and rapidly forming new leaf tissue and hence when the yield of leaf is high; and the percentage is highest when growth is at a low ebb and the leaf tissues present are at a fairly mature stage. Secondly, the dry matter percentage of the Italian ryegrass leaves is consistently some 2% to 4% lower than for perennial ryegrass. In the case of tall fescue, the dry matter percentage corresponds closely to that for Italian ryegrass up to the middle of April, when the increase in its value provides a similar figure to that for perennial ryegrass from early June until the middle of August. The subsequent decline in the dry matter percentage from that period until completion of the experiment again brings the values for tall fescue to approach those for Italian ryegrass. The greater range in dry matter percentages thus shown by tall fescue is a reflection of the much greater yields obtained from this species in comparison with those given by the ryegrasses.

b. Number of live tillers per plant

The number of live tillers recorded for each individual plant at each block lifting is presented in tabular form in Appendix 2, while the mean number of live tillers per plant calculated from the 8 plants of each species at each lifting, is shown in graphical form in figures 2, 3 and 4, for perennial ryegrass, Italian ryegrass and tall fescue respectively.

Inspection of this data reveals that there are obvious differences in tiller numbers per plant between the three species over the experimental period. To elucidate this, an analysis of variance was carried out on this data, and is presented in Table 5.

TABLE 5. Analysis of variance for Number of live tillers per plant over all lifting dates.

Item	Sums of Squares	Degrees of freedom.	Mean Square	F value	F required .05	F required .01	Result
Dates	153,807	16	9,613	3.18	1.97	2.62	**
Species	202,213	2	101,107	33.41	3.30	5.34	**
Dates X species	96,832	32	3,026	2.45	1.50	1.75	**
Residual	418,138	338	1,237				
Total	870,990	388					

In the calculation of this and subsequent two-way analyses of variance where all cells must be occupied, the missing values for dead Italian ryegrass plants were replaced by the mean figure for the particular character calculated from the remaining Italian ryegrass plants at that lifting. While not mathematically correct as using the recognized formula for missing plots (Snedecor, 1946), this procedure was simpler, and any loss in accuracy would be unimportant in view of the further analyses carried out.

The result of this analysis of variance shows that there are highly significant differences in tiller numbers per plant, both between species and between dates, while there is also a highly significant dates X species interaction. The interpretation of this interaction is that the differences between the species do not remain consistent over the whole experimental period, but vary so that the relationships between the species change in statistical significance. The most satisfactory method of elucidating these changes, which are of course important for the purposes of this experiment, is to calculate separate analyses of variance for each lifting date, and thus to determine the relationships between the species for each date. In such one-way analyses as these, it is not necessary to have each cell filled, so that only plants actually examined are included in the analysis, and no "missing plot" calculations are involved. The divisor for the sums of squares, and the degrees of freedom, are adjusted as appropriate. The relevant details of these analyses of variance of the number of tillers per plant at each separate lifting date are set out in Table 6.

TABLE 6. Results of analyses of variance for number of tillers per plant at each separate lifting date.

	Means			Std. Errors		F values				d required	
Date	Ba	Bb	Bn	Ba,Bn	Bb	Actual	.01	.05	Result	.01	.05
4 Dec.	78	25	50	± 4.9	± 4.9	29.91	5.78	3.47	**	19	13
29 Dec.	67	40	46	± 4.7	± 4.7	8.52	5.78	3.47	**	19	14
26 Jan.	84	60	43	± 7.0	± 7.0	8.61	5.78	3.47	**	28	21
16 Feb.	106	38	54	±11.8	±16.6	7.37	6.11	3.59	**	48	35
9 Mar.	144	40	53	±12.8	±12.8	19.55	5.78	3.47	**	51	37
30 Mar.	148	32	64	±12.7	±14.7	20.02	5.93	3.52	**	51	38
20 Apr.	102	36	59	±10.4	±10.4	10.38	5.78	3.47	**	41	30
11 May	146	55	67	±16.6	±16.6	8.84	5.78	3.47	**	67	49
1 June	125	63	72	±13.5	±15.6	4.45	5.93	3.52	*	-	40
22 June	109	68	89	±13.0	±13.0	2.44	5.78	3.47	N.S.	-	38
13 July	139	117	101	±16.0	±20.2	1.46	6.01	3.55	N.S.	-	47
3 Aug.	146	103	79	±14.8	±18.7	5.16	6.01	3.55	*	-	44
24 Aug.	136	103	93	±18.0	±19.3	1.53	5.85	3.49	N.S.	-	53
14 Sept	73	66	75	±13.0	±15.0	0.13	5.93	3.52	N.S.	-	39
5 Oct.	128	58	91	±13.6	±14.5	6.29	5.93	3.52	**	55	40
27 Oct.	74	71	83	±13.9	±13.9	0.22	5.78	3.47	N.S.	-	41
16 Nov.	84	28	81	± 6.4	± 6.8	22.50	5.93	3.52	**	26	19

These results show that at the first lifting on the 4th December, Ba has a highly significantly greater number of tillers per plant than does Bn, and Bn has a highly significantly greater number than Bb. By the 29th December, Ba is highly significantly greater than Bb or Bn, between which there is no significant difference. On the 26th January, the only difference significant at the 1% level is between Ba and Bn, Bb having a value intermediate between these two. However, Bb at this date is significantly less than Ba at the 5% level. Then follows a period through until the 11th May, during which Ba consistently has a greater number of tillers per plant at the 1% level of significance, while there is no difference between Bb and Bn at either the 1% or 5% levels. On the 1st June, the same relationship holds, but is only significant at the 5% level. From the lifting on 22nd June up to and including that on 14th September, the tiller numbers per plant in both Bb and Bn have increased, and while still less than the tiller numbers recorded for Ba, are high enough to prevent statistically significant differences being found. The only exception to this in this period is on the 3rd August, when a small increase in the tiller numbers for Ba and a small decrease in those for Bn, results in a significant difference being discovered at the 5% level between these species. On the 5th October, a small decrease in the tiller number for Bb and a larger increase in both Ba and Bn, results in a highly significant (1% level) difference between Bb and Ba. There are no significant differences at the lifting on 27th October, but at the final lifting on 16th November, a marked decrease in the tiller numbers recorded in Bb results in this species being highly significantly smaller than both Ba and Bn, but there is no difference between these last two species.

A comparison of the curves for mean number of tillers per plant for each species, included in figures 2, 3 and 4, shows that each species had a different shape of curve. Ba increased rapidly from approximately 70 tillers at the beginning of January, to over 140 by early March. Thereafter, with three unexplained anomalous declines, the number of tillers remained of this order until early October, after which they declined rapidly to about 80 at the completion of the experiment. It is possible that the seven month period during which tiller numbers were continually high, may represent saturation point for the pipes; in other words, a total of some 560-580 tillers per pipe is the maximum number which the soil contained in the pipe is capable of supporting with water and nutrients. This contention may be borne out in figure 5, where the average growth rate per tiller for Ba is consistently much below that for Bb. This could be due partly to semi-starvation. In Bb, tiller numbers rose to a minor peak of about 60 at the end of January, and then declined to about 30 at the end of March. This may indicate that in Bb, there is a considerable mortality among the tillers during the autumn period when growth is slow, and it is conceivable that under conditions of competition with other species in a pasture, such mortality among Bb tillers may be a cause of failure of many plants of this species to survive into the winter. An explanation of this nature could underlie the careful management of both Italian ryegrass and short rotation ryegrass (of which Italian ryegrass is one parent) necessary during the autumn if these species are to produce leaf freely over the following winter. From the end of April until the middle of July, tiller numbers per plant increased steadily to the peak value for Bb of nearly 120. This was not maintained, and the number fell off steadily to approximately 60 at the end of the trial, the actual value of 28 at the final lifting on 19th November being due to the very small plants of this species in the last block. In Bn, the number of tillers per plant increased steadily from about 40 during January to 100 by the middle of July, and although this number fluctuated after this date, the trend was for a decrease to about 80 tillers per plant at the end of the experiment.

c. Leaf yield of tillers.

From the combination of leaf yield data and the numbers of live tillers, already discussed, it was possible to obtain some measure of the leaf yield from individual tillers over the course of this experiment. Since the dates of top cuts and of root liftings did not coincide, some adjustment of the data became necessary. It was decided to use the tiller numbers as counted for each lifting date, and to interpolate the leaf yield for these same dates from the curve of dry weight of leaf tissue per plant per day, which has already been explained. It was further decided to use these values as they stood without any attempt at smoothing out irregularities, since these values represent the best estimate available of both tiller numbers and leaf yield at any given date. On the other hand, the resultant leaf yield per tiller curve is derived from this data and is not itself directly measured, so that a smoothed curve can be drawn to show this derived character.

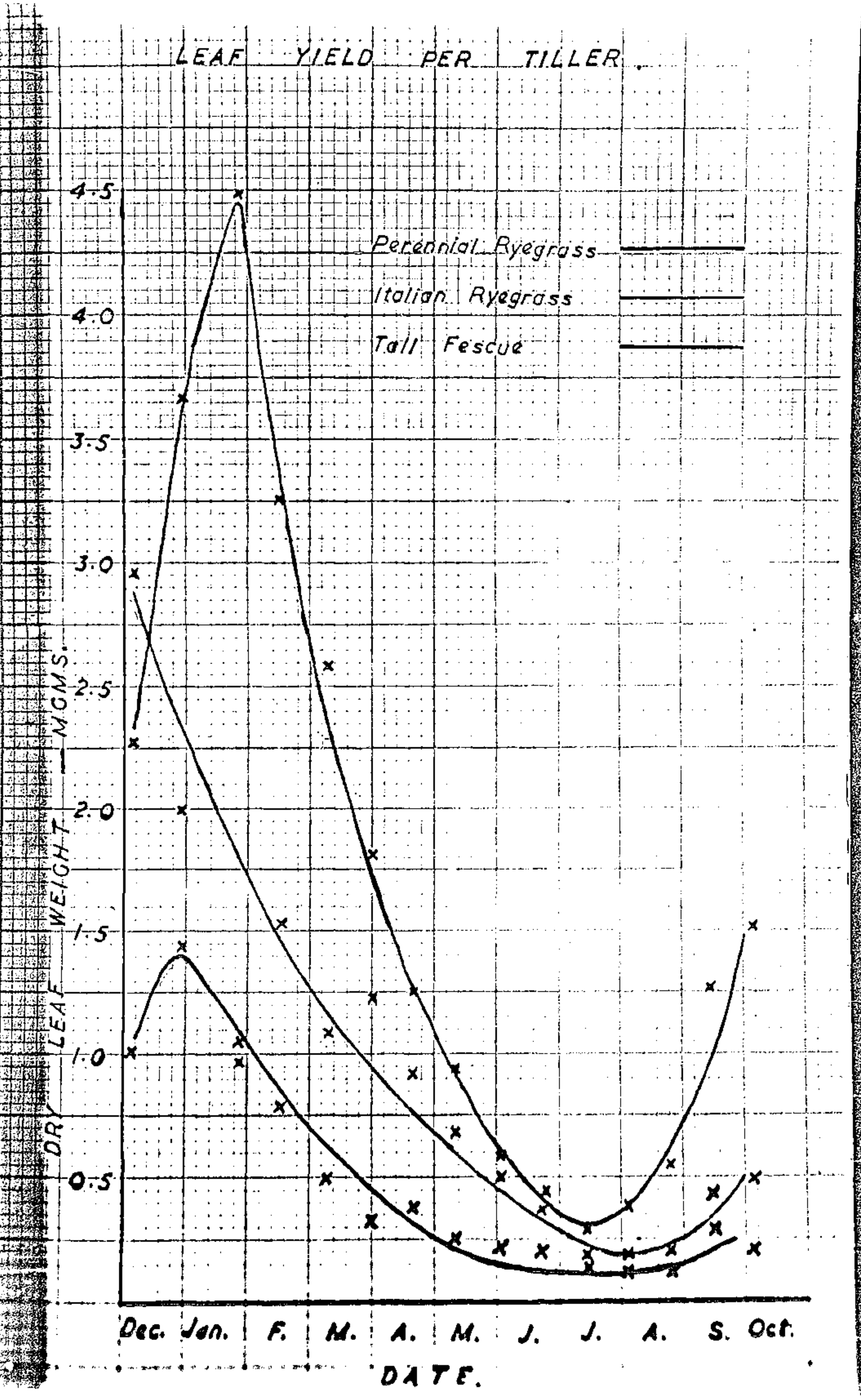
The calculations involved are presented in Table 7, and the curves are shown in Figure 5.

TABLE 7. Calculations of leaf yield per tiller for each species, using actual mean tiller numbers, and interpolated dry weight yields of leaf tissue per plant per day for the same dates.

Date	Perennial ryegrass			Italian ryegrass			Tall fescue		
	No. of tillers	Dry-wt. of leaf. mgm.	Dry-wt. of leaf per tiller. mgm.	No. of tillers	Dry-wt. of leaf. mgm.	Dry-wt. of leaf per tiller. mgm.	No. of tillers	Dry-wt. of leaf. mgm.	Dry-wt. of leaf per tiller. mgm.
4 December	78.0	79	1.01	25.0	74	2.96	50.3	114	2.27
29 December	66.6	96	1.44	40.3	80	1.99	46.4	170	3.66
26 January	84.0	88	1.05	59.6	58	0.97	43.1	193	4.48
16 February	105.8	83	0.78	37.8	58	1.53	54.4	177	3.25
9 March	143.9	70	0.49	40.4	44	1.09	52.5	136	2.59
30 March	147.8	48	0.32	32.4	40	1.23	64.0	116	1.81
20 April	101.5	39	0.38	35.8	33	0.92	59.0	74	1.25
11 May	146.3	37	0.25	55.4	38	0.69	67.3	63	0.94
1 June	125.4	26	0.21	62.6	31	0.50	72.3	42	0.58
22 June	108.6	22	0.20	68.3	29	0.42	89.1	33	0.37
13 July	138.5	19	0.14	116.6	27	0.23	101.0	28	0.28
3 August	145.8	17	0.12	103.2	24	0.23	79.1	31	0.39
24 August	136.1	16	0.12	103.6	25	0.24	93.3	51	0.55
14 September	73.3	21	0.29	65.5	29	0.44	75.4	95	1.26
5 October	128.0	26	0.20	57.7	28	0.49	90.9	137	1.51

FIGURE 5.

Leaf yield per tiller, derived from mean tiller numbers and interpolated dry weight yields of leaf tissue per plant per day for the same dates, in perennial ryegrass, Italian ryegrass, and tall fescue.


LEAF YIELD PER TILLER.
Perennial Ryegrass
Italian Ryegrass
Tall Fescue
DRY LEAF WEIGHT — MGMS.
4·5
4·0
3·5
3·0
2·5
2·0
1·5
1·0
0·5
Dec. Jan. F. M. A. M. J. J. A. S. Oct.
DATE.

In Ba, the peak rate of leaf yield per tiller (1.4 mgm. of leaf tissue per tiller per day) is reached at the end of December, after which the yield falls off rapidly at first and then more slowly until the beginning of June, when the minimum values of some 0.15 to 0.20 mgm. leaf tissue per tiller per day are reached. This level holds until the end of August, and during September there is an increase in the leaf yield per tiller. All plotted points for Ba are within reasonable distance of the curve. The fact that the whole curve for Ba has only some 50-60% of the values for the corresponding curve for Bb may be evidence that growth of the Ba plants in the pipes was being affected by overcrowding of the tillers. The yield peak in Bb was reached either at or before the first lifting on 4th December, and from a value at that date of 3 mgm. of leaf tissue per tiller per day, there is a steady fall, rapid at first and then rather slower, to the minimum value of about 0.25 mgms. by the middle of July. This held until the end of August, and the growth rate increased again during September. The dispersal of some of the plotted points for Bb before April is due to the variations already noted in tiller numbers in this species. The evidence here is that the reduced yield of Bb in autumn in comparison with Ba, can be at least partly explained on the grounds of tiller mortality in Bb, rather than upon a reduced rate of leaf growth from the tillers in this species. In Bn, the distribution of points shows that the yield peak is reached near the end of January, when there is an average of some 4.5 mgm. of dry leaf tissue being formed daily by each tiller. This peak corresponds to the maximum leaf yield found in Bn, and is not maintained. It decreases rapidly and steadily to a minimum value of 0.28 milligrams at the middle of July, and thereafter immediately rises again during August. In comparison with the two ryegrasses, this leaf yield per tiller curve for Bn shows the same two features as appeared in the leaf yield curve; that is, the spectacular yielding ability, and the short winter period during which growth is at a relatively low ebb. It may be noted that the leaf yields per tiller for Ba and Bb are fairly similar from the middle of June to mid-July, and the rate for both these species is higher than that for Bn.

d. The relationship between leaf yield and tiller numbers in each species

An inspection of figures 2, 3 and 4 shows that there is an apparent inverse relationship between the leaf yield expressed as dry-weight of leaf tissue per plant per day, and the number of tillers per plant, in each of the three species studied. To determine whether or not there was a significant relationship between these two characters, correlation coefficients were calculated for each species, and the results are given in Table 8, while scatter diagrams for the same data are shown in Figure 6. Since the dates on which the top cuts and the root block liftings were taken did not coincide, the interpolated dry weight yields of leafage for the same dates on which tiller counts were made, were used in the calculation of these correlation coefficients.

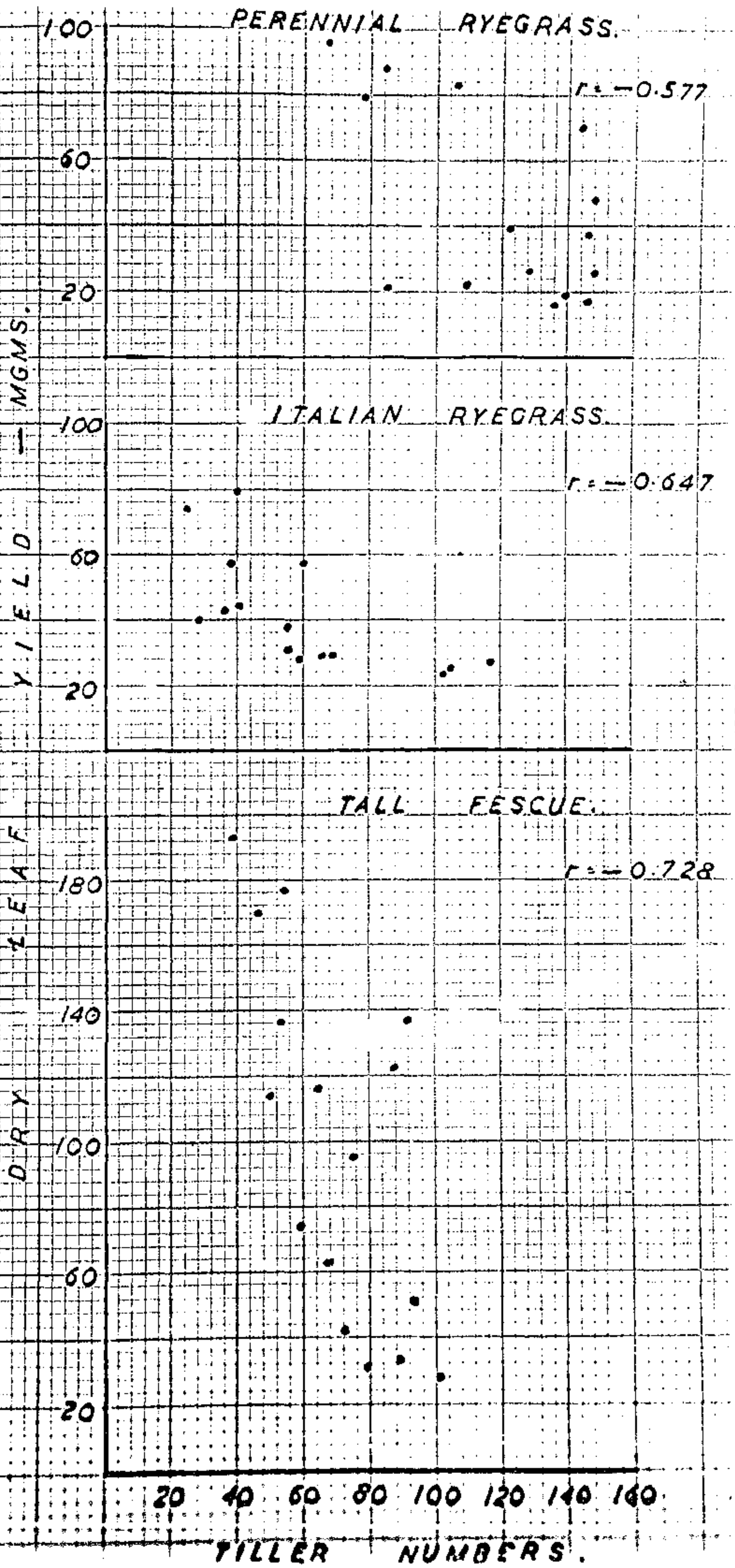
TABLE 8. Correlation coefficients between numbers of tillers per plant, and the interpolated dry weights of leafage per plant per day for the same dates.

	Values of r.			Result of test.
	Actual	Required at 5% level	Required at 1% level	
Perennial ryegrass	- 0.577	0.514	0.641	*
Italian ryegrass	- 0.647	0.514	0.641	**
Tall fescue	- 0.728	0.514	0.641	**

These results show that in the case of both Italian ryegrass and tall fescue, there is a negative correlation, significant at the 1% level, between leaf yield and number of tillers per plant. With perennial ryegrass, there is also a negative correlation, but significant only at about the 3% level. This reduced level of significance can be explained on the behaviour of the tillers in perennial ryegrass, which increased rapidly to a maximum in early March and maintained this high level until the middle of August, while the leaf yield curve

FIGURE 6.

Scatter diagrams for mean tiller numbers per plant, and interpolated dry weight yields of leaf tissue per plant per day for the same dates, in perennial ryegrass, Italian ryegrass, and tall fescue.



PERENNIAL RYEGRASS.
r = −0.577
ITALIAN RYEGRASS.
r = −0.647
TALL FESCUE.
r = −0.728
DRY LEAF YIELD — MGMS.
100
60
20
100
60
20
180
140
100
60
20
20 40 60 80 100 120 140 160
TILLER NUMBERS.

declined from late January to early June and reached its minimum during July and August. In Italian ryegrass, the reduction in tiller numbers found during February and March while leaf yield was also declining, will have reduced the correlation coefficient, although the calculated value is high enough to give significance at the 1% level.

The result of this test in each species shows that as leaf yields decrease during the autumn and winter periods, numbers of live tillers present on each plant increase, and that the tiller numbers decline again in spring as leaf growth commences for the new season. A discussion and explanation of this relationship is given in a later section (see Discussion: 5. Relationships in the top growth measurements).

...

B. General Description of the Root Systems.

This section of the results will be presented in three parts, as follows:-

a. a description of the condition of the root tissues as observed at each lifting.

b. a description of the root staining patterns obtained from the use of tetrazolium salt.

c. an analysis of the dry matter percentages for both white roots and roots other than white in all three species, together with a statement of the crude fibre percentages in both classes of roots in the three species.

In this section of the results, and in the succeeding sections on root numbers and weights, and on the relationships between roots and leaf yields, two classes of roots will be considered. These classes are "white roots", and "roots other than white roots". The o.t. white roots were those which became noticeable from the 9th March lifting onwards, because of their colour and other characters and which were separated from, counted and weighed as a separate group, for each plant over the remainder of the experimental period. Roots other than white roots composed the remainder of the root system of each plant. This classification is somewhat artificial, and no attempt was made to sort the roots other than white roots into any component types. Never-the-less, it can be contended that the classification adopted here is adequate for the purposes of this experiment. These were essentially two in number; firstly, to study the behaviour over a twelve-month period of the total root system of the plants of the three species concerned, and "roots other than white roots" allowed this to be done; secondly, to study new root formation over the same period, and the "white roots" provided a measure of root initiation. The question of classification of roots into component classes is dealt with in a later section (see Discussion: 2. Root classes and staining patterns with tetrazolium salt).

a. Condition of the root tissues.

In perennial ryegrass, roots at the liftings during December were pale cream in colour, but on 26th January a definite darkening had occurred and the root system was light brown. On this same date, it was noticed that the root cortex in many cases had softened in the proximal region nearest the crown, and was tender to pressure of the fingers. A firm pressure was enough to rupture the cortex, which then appeared to separate freely from the underlying stelar tissues. This same tenderness was found on 16th February, and at the fifth lifting on 9th March, some roots were showing natural tearing and loss of cortex over an inch or inch and a half of root near the crown. By 30th March, loss of cortex extended over some 3 or 4 inches of root in the proximal region, and over the remaining liftings the length of root from which the cortex layer had sloughed off was in excess of six inches. In any plant, however, there was considerable variation between roots in the degree of cortex sloughing present, and at any lifting, it was not possible to form any clear classification of cortex sloughing because of the continuous nature of this variation. In roots which had lost their cortical tissue, the stele remained intact, joining the distal part of the root carrying root hairs and laterals and an intact cortex over several inches of length behind the root tip to the crown of the plant. By the 20th April, both stele and cortex, when present, were fairly dark brown in colour and reached a very deep brown colour during July.

In Italian ryegrass, the pattern is essentially the same as in perennial ryegrass, with one important exception. The proximal cortex was found to be tender and tearable to finger pressure on some roots at the lifting on 29th December, some 4 weeks before the same feature was noted in perennial ryegrass. This suggests that the older roots in Bb are undergoing deterioration at an earlier stage than in Ba, and may be part of the explanation for the decrease in numbers of roots other than white roots recorded in Bb during March and April (see section 3 of the Results). Bb plants were showing natural tearing of the cortical tissues during March, this being noticeable at first in the proximal inch or so, but rapidly spreading over a much greater proportion of the root length. The colour changes to dark brown paralleled those found in Ba.

At the 4th lifting on 16th February, one Bb plant showing complete death of all top tissue was carefully cleaned and examined. The root system was very tender and many roots had obviously broken during washings, the cortex on every root was loose and had mostly sloughed free of the stele, while the stele itself was brittle and readily broke if any tension was applied to it.

In tall fescue, the cortex was first noticed as being tender to finger pressure at the lifting on 26th January, and there was natural loss of cortex on 30th March and at subsequent liftings. Discolouration of the roots was noticed during February, and became progressively greater. These dates correspond with those in Ba, except that the actual loss of cortex in Bn was 3 weeks later. Individual Bn roots were much thicker than in the ryegrasses, and this root size may have had some bearing on the apparently greater resistance of the Bn cortical tissue.

In all three species, white roots were first detected as a separate class at the fifth lifting on 9th March. The white roots were stout and shiny, unbranched and straight, and were rarely more than eight inches long, being frequently much shorter than this. They were present at all liftings following their first recognition, the discolouration of the older roots allowing easy identification because of their creamy-white colour. Their lack of branching allowed free separation from the remainder of the root system.

The loss of the "white" condition was observed in several cases, but may not be typical of the changes occurring in all white roots. It was only seen at the root liftings so that no measure of the time these changes took could be obtained, although since only three or four roots per plant were affected at any lifting date, the duration is probably fairly short. Browning of these white roots commenced at foci spaced at approximately one inch intervals along the roots, and spread to either side of these foci. This led to a banded appearance, white alternating with brown. Finally, the entire root was brown, and presumably entered a phase which would end with tenderness and loss of the cortex.

b. Staining patterns with tetrazolium salt

Before the first root liftings were made, small-scale trials were carried out to determine a suitable concentration of the tetrazolium salt and also a satisfactory temperature and duration for the staining reaction. The plant material used here was mainly young single plants of Poa annua and perennial ryegrass growing on the outskirts of the plot area. These were dug out and carefully washed before treatment.

The results of this preliminary work indicated that a 1.0% concentration of the tetrazolium bromide in distilled water (actually 1 gram of salt to 100 millilitres of water) was sufficient to stain root tissues. This is the same concentration as is recommended for use as an indicator of seed germination, and has proved satisfactory with chaffy grass seeds. It was further found that adequate staining resulted from root immersion at 30°C for 8 hours. This temperature was chosen largely because an incubator set at the controlled temperature of 30°C was available, and this also provided darkness. Since the tetrazolium salt is not light-stable, the reaction must take place in darkness. The time of 8 hours for the reaction was sufficient, a comparison with staining patterns obtained over longer periods showing that further immersion did not give any clearer indications.

In this preliminary work, it was also necessary to prove that dead root tissues did not stain. For this purpose, young plants of perennial ryegrass and Poa annua were used, the root tissues being killed by exposure of the crown and root system of each plant to boiling water for four minutes. These plants were then placed in tetrazolium solution for 8 hours, together with untreated similar plants. In no case was there any sign of roots being stained after the tissues were dead, while normal staining took place in the untreated control plants.

The staining pattern obtained in the root systems of these young plants was quite consistent over the material used in this experiment. The root tip and approximately 1 mm. of root immediately behind the tip stained a dense red colour. Young emerging lateral roots up to approximately ½ inch in length showed a similar dense red colouration, indicative of intense biological activity. Older lateral roots showed this dark staining only in the region near the tip. The stele or vascular cylinder stained consistently over its entire length, although the depth of colour developed was never so intense as at the root tip. The cortex failed to stain, or at the most presented a very pale pinkish colouration, and in these entire roots, the stele could be seen with the naked eye underlying the cortex.

At the later liftings, when the cortex had separated from the stele over the proximal part of the root, the stele still stained over its full length, indicating that loss of cortical tissue did not mean the death of the entire root, or that it ceased to function as an integral part of the plant. Unfortunately, as the root tissues darkened with age, it became increasingly difficult to recognize the red colouration from the reduced tetrazolium salt, or formazan, and at the liftings on 1st and 22nd June and 13th July, no staining pattern could be detected by the naked eye, and examination under a low-power (X 10) binocular microscope was essential. After 13th July, tetrazolium staining was discontinued, since root tissues were of such a dark brownish colour that satisfactory descriptions of the staining results could no longer be made. By that time, however, it had been demonstrated that individual roots remained functional after the loss of much of the cortex tissue, the stele continuing to serve as conducting tissue connecting the distal region of lateral roots and root hairs to the crown of the plant. It is likely that these roots remain functional until the stele itself is broken.

The staining pattern in white roots took a rather different form. There was an intense deep red stain developed at the root tip and for about 1 mm. behind this, indicating intense activity in this region.

The cortical tissues were opaque, and took up a pink stain over their whole length, although frequently the intensity of the staining showed gradual variations over a distance of 2 to 3 inches. The opaque nature of the cortex prevented any naked-eye inspection of the underlying stelar tissues. The general staining pattern in white roots was suggestive of considerable biological activity taking place in these young tissues.

The staining patterns described above were observed in all three species under trial, although the greater thickness of Bn roots made observations more difficult in this species than in the ryegrasses.

c. Root dry matter percentages.

Differences between the two root classes considered in this experiment - "white roots" and "roots other than white roots" - have been described on the bases of colour, condition of the cortex tissues, and staining patterns developed from reaction with tetrazolium salt. Since fresh weights and dry weights were available for the two root classes of each individual plant from the 20th April lifting until completion of the experiment, it was decided to calculate the dry matter percentages of the root tissues. These percentage figures could then be subjected to statistical analysis, to determine any real differences between the root classes in their dry matter contents.

The dry matter percentages for each plant are set out in Appendix 2, while the mean values for each species at each lifting are shown in figure 7. For each species, it can be seen that the roots other than white roots had a dry matter content higher by some 10% than that of the white roots. It can also be seen that within each class of root, the values for each species change their relationships to the others over the experimental period. Thus, in white roots, Bn has a higher dry matter percentage than either Ba or Bb until 24th August, and after this date, Bb has a rather higher percentage and Ba becomes similar to Bn.

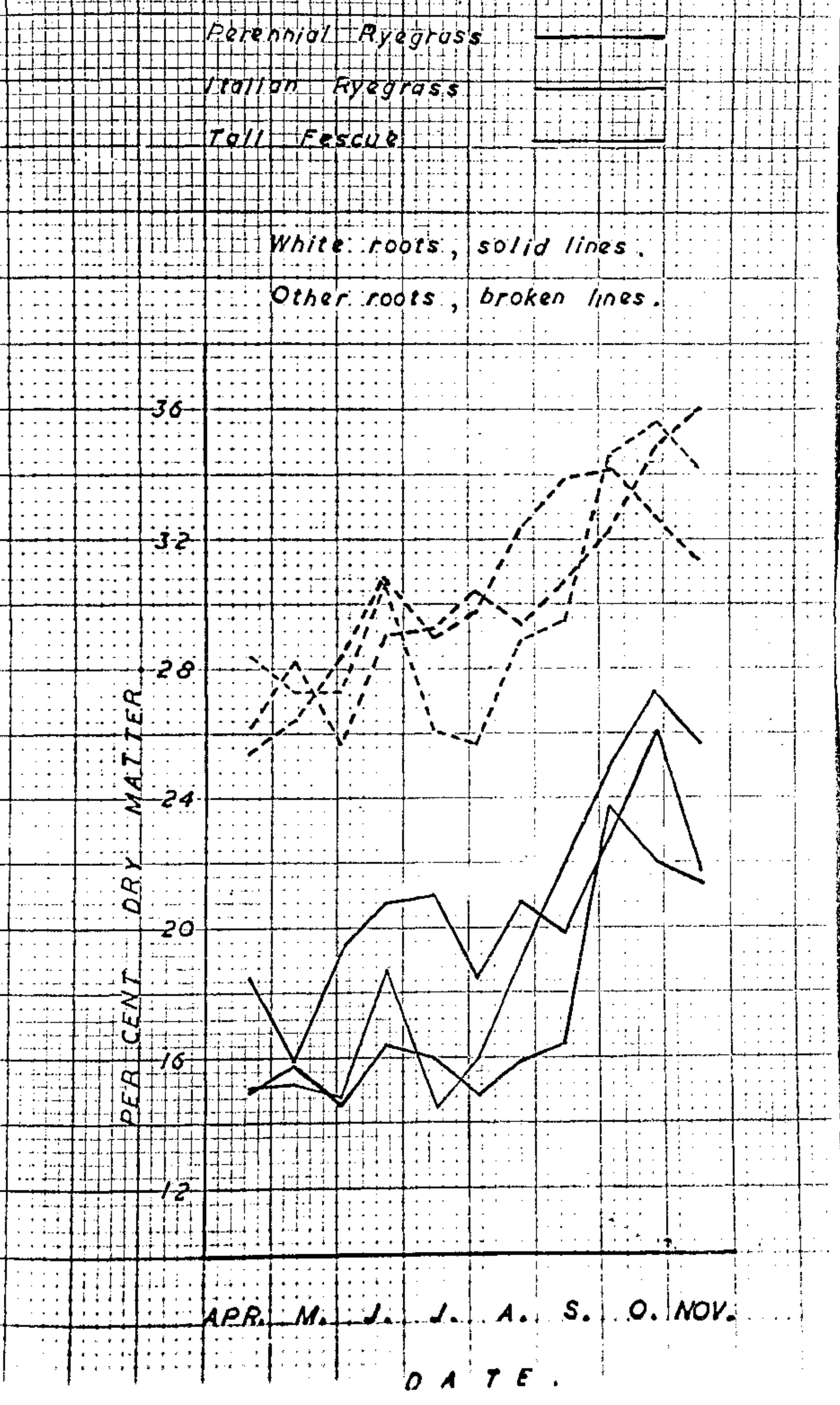
Two periods of distinct trends can be seen in figure 7. Up to, and including, the lifting on 3rd August, the dry matter percentages in each case remain either steady, approximating their original value, (white roots in 3 species, and roots other than white roots in Bb), or else show a small increase (roots other than white roots in Ba and Bn). From the lifting on the 24th August until the end of the experiment in mid-November, there is in every case, with the apparent exception of roots other than white roots in Bn, a greater rate of increase in the dry matter percentage of the root tissues.

FIGURE 7.

The dry matter percentages for white roots and for roots other than white roots, in perennial ryegrass, Italian ryegrass, and tall fescue.

FIGURE 1.

ROOT DRY MATTER — PER CENT.



Since with each species, the dry matter percentages of the white roots were consistently less than those of the roots other than white roots, the trends just described could be ignored for the purposes of the statistical analysis. This avoided the necessity of recalculating an analysis for each lifting date. The mean dry matter percentages for both root classes for each species, together with the standard errors of those means, were calculated; and the differences between the dry matter percentages of the two root classes in each species were then tested for significance by the use of the "t" test (Snedecor, 1946). The relevant figures, and the result of this test, are set out in Table 9.

TABLE 9. Means, standard errors, and tests of significance of the differences between means, for the dry matter percentages of white roots, and roots other than white roots, in the three experimental species.

Species	Roots other than white roots		White roots		"t" Test			
	Mean	S.E.	Mean	S.E.	Degrees of freedom	t. actual	t.01	Result
Ba	30.70%	± 0.20%	17.29%	±0.38%	147	30.203	2.610	**
Bb	30.93	± 0.30	18.79	±0.35	122	24.979	2.617	**
Bn	30.50	± 0.15	20.31	±0.34	147	26.816	2.610	**

The results shown in Table 9 indicate that in each species, the white roots have a highly significantly lesser dry matter percentage than the roots other than white roots. This is consistent with the white roots being composed of younger tissue than the roots which have lost their "white" characteristics.

Further evidence became available from analyses for crude fibre percentages of each root class in each species, carried out in the Biochemistry Department, Massey College. The samples analysed were bulked dry samples from the liftings on 13th July, 3rd August, and 27th October. Results are set out in Table 10.

TABLE 10. Percentages of crude fibre in white roots and roots other than white in bulked samples for each experimental species.

Class	Ba	Bb	Bn
White roots	35.2%	34.3%	32.6%
Roots other than white roots.	42.1	38.4	43.1

While these crude fibre percentages in Table 10 were made as single determinations, and are therefore likely to contain concealed errors, they show that for each species, the crude fibre percentage of the white roots is at least 4% less than that of the roots other than white roots. This is consistent with white roots being composed of younger tissue, and suggests that the white roots may be more concerned in conduction of metabolites than in support or anchorage of the plant.

C. Root Numbers and Weights

This section of the results will present analyses of the data assembled from the various measurements made on certain root characters. At the lifting of each block, records were made of the number of roots from each plant, together with the number of white roots from the fifth lifting on the 9th March until the completion of the experiment. Full oven-dry weights of both classes of roots for every individual plant were not taken until the seventh lifting on 20th April, but were determined from then until the end of the trial.

The analyses made of this data will be set out in ten sub-sections, as follows:

(a) the number of roots other than white roots per plant.

(b) the dry weight of roots other than white roots per plant.

(c) the number of roots other than white roots per tiller.

(d) the dry weight of roots other than white roots per tiller.

(e) the number of white roots per plant.

(f) the number of white roots per plant as a percentage of the number of total roots per plant.

(g) the dry weight of white roots per plant.

(h) the dry weight of white roots per plant as a percentage of the dry weight of total roots per plant.

(i) the number of white roots per tiller.

(j) the dry weight of white roots per tiller.

(a) Number of roots other than white roots per plant.

The measurements for individual plants are set out in Appendix 2 for each lifting, and the mean values for each lifting are graphed in figures 8, 9, and 10 for Ba, Bb, and Bn respectively.

A normal analysis of variance was calculated for this data, and the result is presented in Table 11. As in all cases with these general analyses of variance, missing values for Bb plants were supplied by the use of the mean value of the Bb plants present at each particular lifting, and the necessary adjustments were made in the number of degrees of freedom. It should be noted that since white roots were not recognizable as a separate class until the fifth lifting on 9th March, the number of roots other than white roots is simply the total count of roots during the first four liftings. From the lifting on the 9th March until the completion of the experiment, the number of roots other than white roots for each individual plant is the difference between the total number of roots and the number of white roots present in that plant.

TABLE 11. Analysis of variance for number of roots other than white roots per plant over all lifting dates.

Item	Sums of Squares	Degrees of freedom	Mean Square	F value	F required .05	F required .01	Result
Dates	430,159	16	26,885	1.82	1.97	2.62	N.S.
Species	1,274,119	2	637,060	43.16	3.30	5.34	**
Dates X Species	472,284	32	14,759	2.61	1.50	1.76	**
Residual	1,910,151	338	5,651				
Total	4,086,713	388					

The results of this analysis of variance showed that the differences in this root character between dates approached but did not quite reach significance at the 5% level, but that the differences between the species were more than significant at the 1% level. There was also

FIGURES 8, 9, 10.

The number and dry weight of roots other than white roots, and the number and dry weight of white roots per plant in perennial ryegrass, Italian ryegrass and tall fescue respectively.

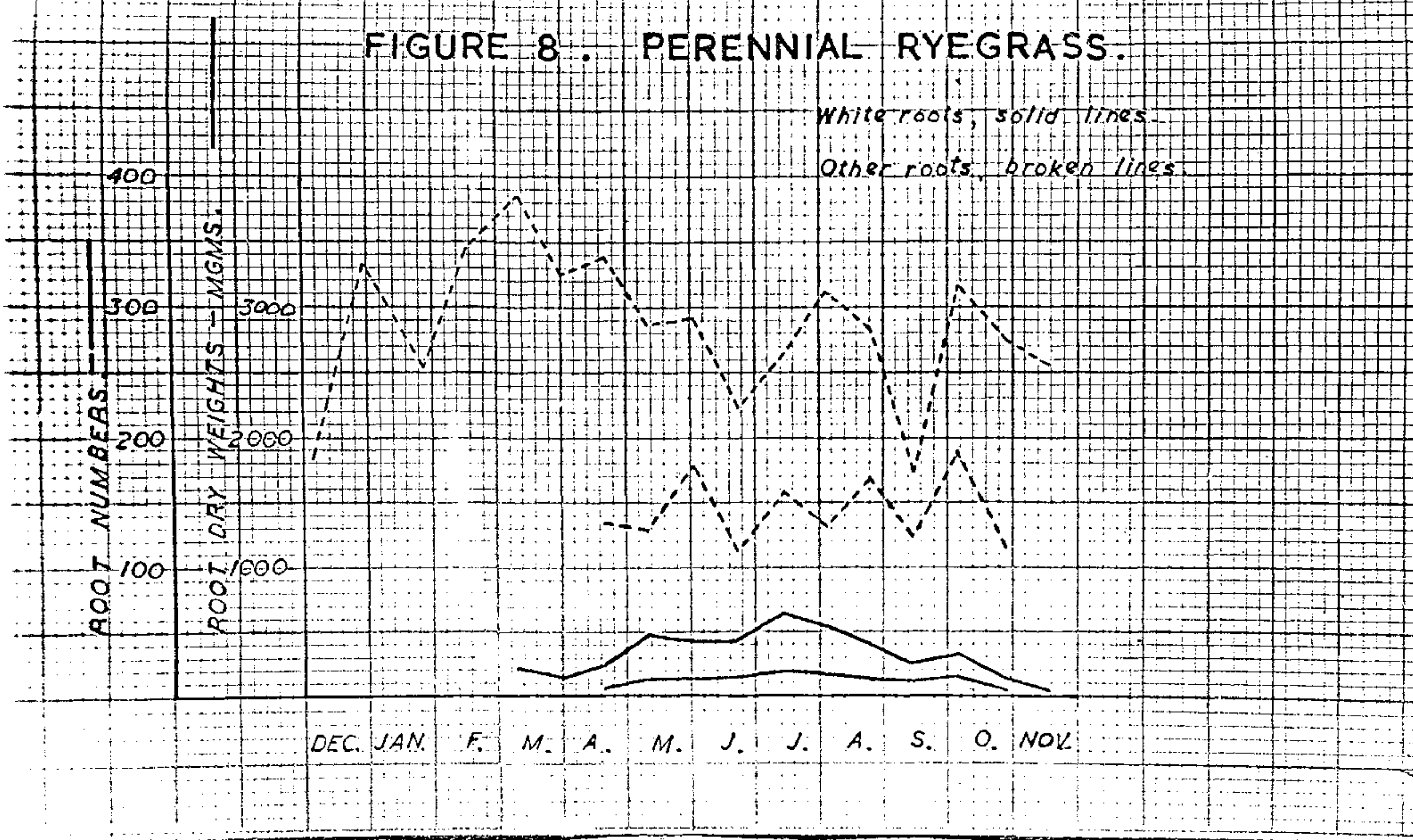


FIGURE 8. PERENNIAL RYEGRASS.
White roots, solid lines.
Other roots, broken lines.
ROOT NUMBERS.
ROOT DRY WEIGHTS – MGMS.
400
300
200
100
3000
2000
1000
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FIGURE 8.

FIGURE 9. ITALIAN RYEGRASS.

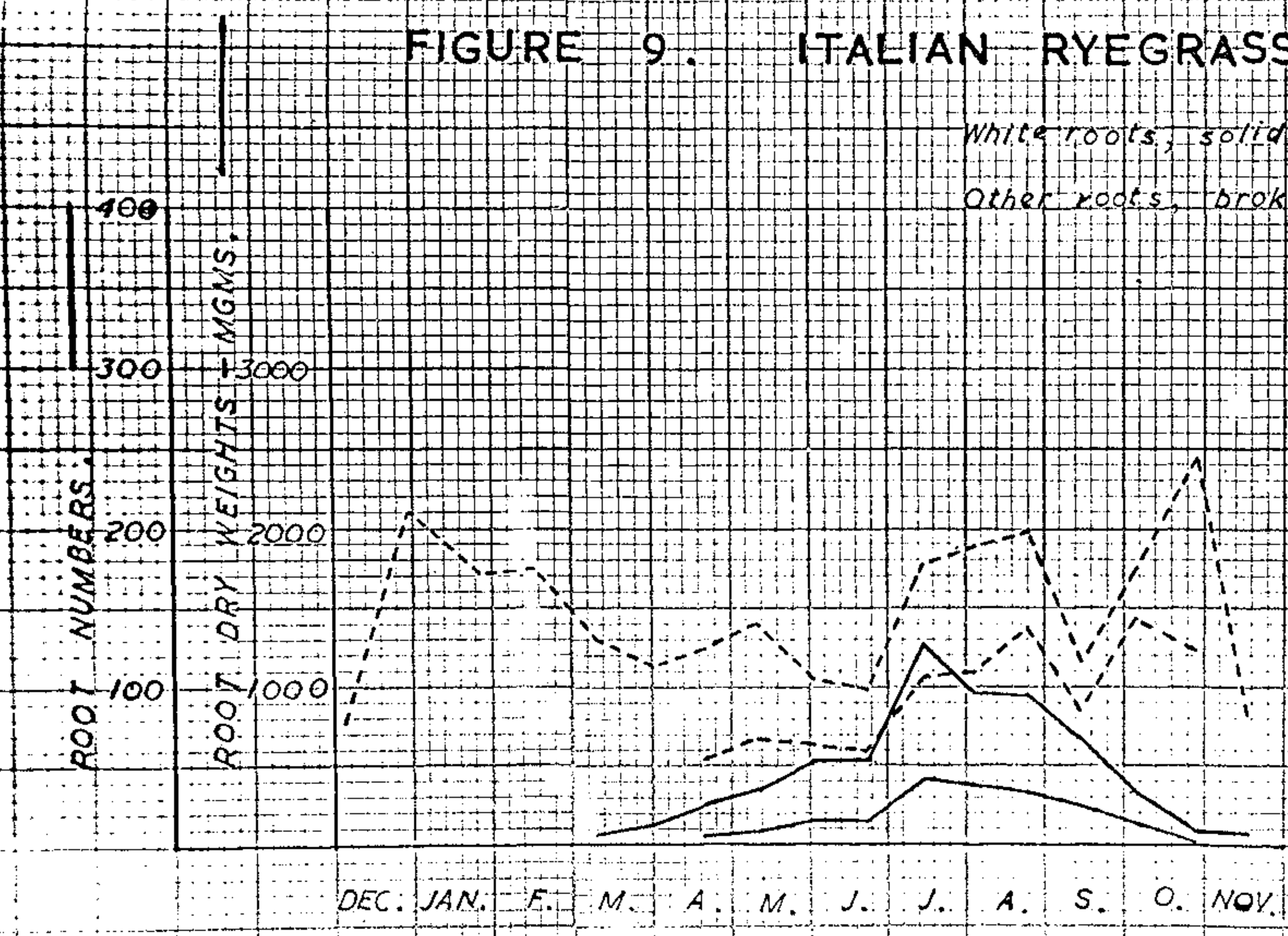


FIGURE 9.

FIGURE 10. TALL FESCUE.

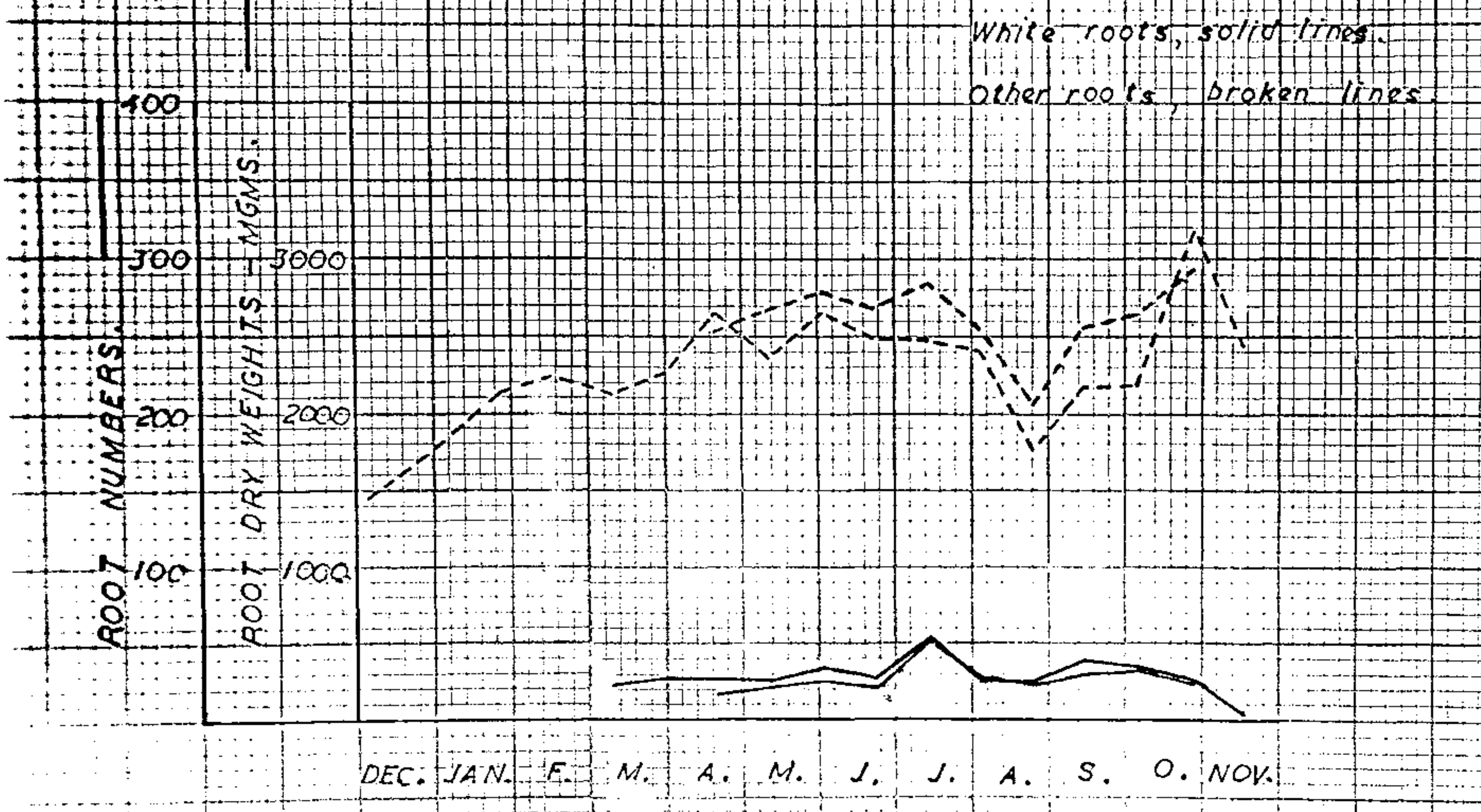


FIGURE 10.

a highly significant interaction between dates and species, indicating that the differences in this root character between the species was not constant, but varied over the experimental period. To examine the nature of this variation, analyses of variance of the number of roots other than white roots per plant were calculated for each lifting date, and the relevant results are set out in Table 12.

TABLE 12. Results of analyses of variance for number of roots other than white roots per plant, at each separate lifting date.

	Means			Std. Errors		F values				d required	
Date	Ba	Bb	Bn	Ba,Bn	Bb	Actual	.01	.05	Result	.01	.05
4 Dec.	183	77	146	± 9.8	± 9.8	30.0	5.78	3.47	**	40	29
29 Dec.	332	210	173	±20.9	±20.9	15.7	5.78	3.47	**	84	62
26 Jan.	254	171	212	±19.6	±19.6	4.60	5.78	3.47	*	-	57
16 Feb.	345	175	224	±35.4	±50.1	4.79	6.11	3.59	*	-	106
9 Mar.	384	130	211	±23.9	±23.9	29.62	5.78	3.47	**	95	70
30 Mar.	325	112	226	±30.0	±34.6	10.07	5.93	3.52	**	121	89
20 Apr.	339	124	265	±29.4	±29.4	13.76	5.78	3.47	**	117	86
11 May	287	140	237	±27.5	±27.5	7.35	5.78	3.47	**	110	81
1 June	291	105	264	±21.5	±24.9	16.96	5.93	3.52	**	87	64
22 June	222	99	249	±25.1	±25.1	10.18	5.78	3.47	**	101	74
13 July	265	177	248	±27.4	±34.7	2.08	6.01	3.55	N.S.	-	82
3 Aug.	311	188	240	±39.8	±50.4	1.95	6.01	3.55	N.S.	-	118
24 Aug.	283	199	177	±22.3	±23.8	6.29	5.85	3.49	**	90	66
14 Sept	172	117	218	±24.3	±28.1	3.72	5.93	3.52	*	-	72
5 Oct.	317	175	219	±30.5	±32.6	5.46	5.85	3.49	*	-	90
27 Oct.	275	243	317	±37.3	±37.3	0.97	5.78	3.47	N.S.	-	110
16 Nov.	257	82	244	±14.7	±15.7	40.23	5.85	3.49	**	59	43

In all three species, the pattern followed by this root character is rather variable, but as would be expected, it is essentially similar to the pattern of tiller numbers per plant. With Ba, the number of roots other than white roots reached a peak value by early March of the order of 350 roots per plant, maintained this peak until late in April, and declined to a value between 250 and 300 until the end of the trial, although certain liftings gave root numbers a little outside these limits. With Bb, the number of roots other than white per plant remained at a value of about 170 during January and early February, but then declined sharply and fluctuated around 120 roots from early March until late in June. This sudden decrease in March is not due to the recognition of white roots as a separate class from 9th March onwards, since mean values of white roots of only 6.6 per Bb plant were counted on 9th March, 12.1 on 30th March, and 26.0 on 20th April. The sudden decrease was associated with the decline in tiller numbers over this period, so that the figures found for Bb show that loss of both photosynthetic and root tissue was considerable under these experimental conditions. There is evidence in these counts made for this species of a definite period in autumn when loss of older roots is considerable but the formation of new white roots is still at a low ebb. This period is a critical one in the survival of Bb plants into the winter. From early in July, there is an increase in root numbers to nearly 200 per plant, due largely to the ageing of white roots which were being formed in considerable numbers after the end of April. This would suggest that in Bb at least, white roots retain their characteristics for some 6 to 9 weeks during the winter before ageing symptoms lead to their exclusion from the white root class. With Bn, numbers of roots other than white roots increased steadily to about 220 per plant by the middle of January and this value was maintained until the end of March. There was a small further increase to about 250 roots per plant during April, due to the formation of white roots during March (21.1 per plant on 9th March and 28.8 per plant on 30th March being recorded), and this remained relatively constant until early in August. The number of roots then declined to around 200 per plant during August and September, but had recovered to some 250 when the experiment ended.

The analyses of variance in Table 12 show that on 4th December, Bb has significantly less roots other than white roots than have Ba or Bn at the 1% level, while Bn has significantly fewer than Ba at the

5% level. By 29th December, both Bb and Bn are less than Ba at the 1% level of significance. On 26th January, the only significant difference (at the 5% level) is that Bb has fewer roots per plant than Ba, while on 16th February, both Bb and Bn have significantly fewer roots than Ba at the 5% level. On 9th March, both Bb and Bn are significantly less than Ba at the 1% level, while Bb is significantly less than Bn at the 5% level. On 30th March, the only significant difference at the 1% level is that Bb is less than Ba, while at the 5% level for this date, Bb is less than Bn which in turn is less than Ba. On 20th April, Bb is significantly less than both Ba and Bn at both levels. On 11th May, this same relationship holds at the 5% level, but at the 1% level, Bb is only less than Ba. On both 1st and 22nd June, Bb is less than Ba and Bn at both levels of significance. No significant differences appeared in the lifting on 13th July and 3rd August, due to the increase at this time of the root numbers in Bb. On 24th August, Bn has less roots than Ba at the 1% level of significance, and both Bn and Bb have significantly fewer at the 5% level. On 14th September, Bb has fewer roots than Bn at the 5% level, and both Bb and Bn have significantly fewer roots than Bn at the 5% level on 5th October. No significant differences existed in the lifting on 27th October, but at the final lifting on 16th November, the small size of the Bb plants led to this species having fewer roots than Ba or Bn at both levels of significance.

While the relationships tend to be variable during the course of the experiment, the important feature is that the number of roots other than white roots per plant in Bb is significantly less than in Ba from the start of the trial on 4th December, until the lifting on 13th July. With only 5 exceptions (29th December, 22nd June, 24th August, 14th September and 27th October), Ba possessed more of these roots than Bn which in turn had higher numbers than did Bb.

(b) Dry weights of roots other than white roots per plant.

The dry weights of roots other than white roots are given for plants of each species at each lifting in Appendix 2, and the mean values for this root character at each lifting are shown in Figures 8, 9 and 10 for Ba, Bb and Bn respectively.

The analyses made of differences in dry weights between the three species for various root classes are subject to one factor which does not enter into the analyses based on numbers. This factor is the differences which exist between individual root weights from the three species. To show this more clearly, the total dry weight of roots for each species at each lifting was divided by the total number of roots for that species at the same lifting, and the resultant mean dry weights per individual root are shown in Figure 11.

An examination of this figure shows that in the case of roots other than white roots, the mean dry weight of the individual Bn root ranges between 10 and 12 milligrams, of the Bb root between 5 and 7 milligrams, and of the Ba root between 4 and 6 milligrams. Over the period, the individual Ba root other than white root, has a dry weight approximately 1 milligram less than Bb, which in turn is about half the weight of the individual Bn root. In the case of white roots, the variation in dry weight of the individual root in Bn is from 7 to 10 milligrams, while in both Bb and Ba, the individual white root has a dry weight between 2 and 4 milligrams. Over the period, the individual dry white root weights in Ba and Bb are approximately one-third of those in Bn. Two other points should be noticed in this figure 11. Firstly, in each species, with the possible exception of Bn white roots, there is an apparent tendency for individual root dry weights to increase from April until early October, followed by a sharp decline. This latter decline corresponds in Ba and Bb with the spring period when leaf growth rate is increasing rapidly, but this tendency is not so well marked in Bn where the

FIGURE 11.

The average dry weight of individual roots other than white roots, and of individual white roots, in perennial ryegrass, Italian ryegrass and tall fescue.

FIGURE 11.

DRY WEIGHT OF INDIVIDUAL ROOTS.

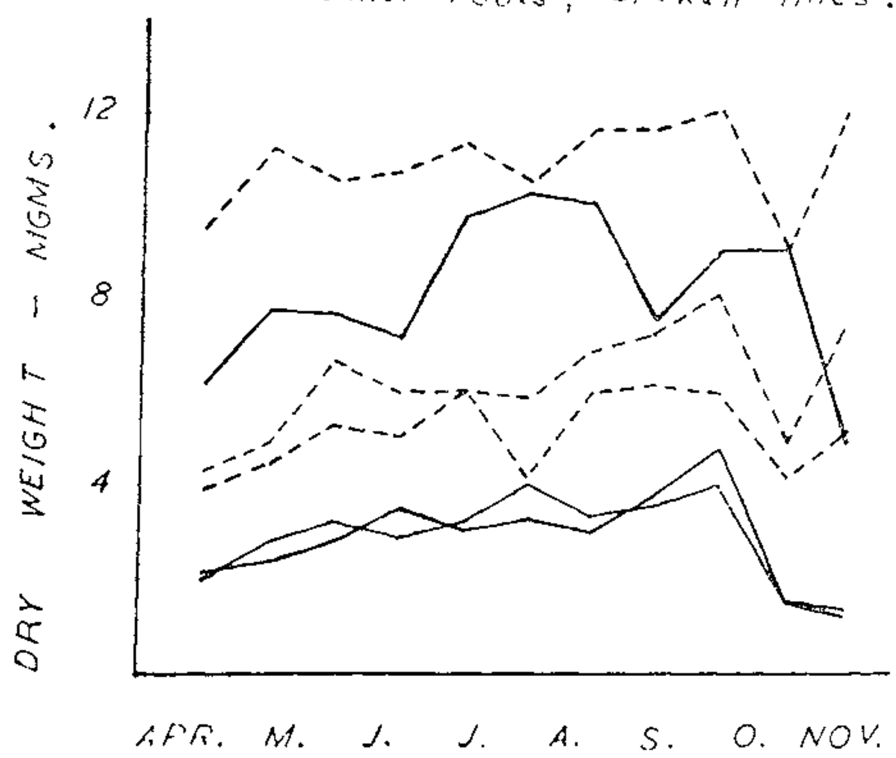
Perennial Ryegrass.

Italian Ryegrass.

Tall Fescue.

White roots, solid lines.

Other roots, broken lines.



leaf growth rate increased from August. The decline in Bn white root weight was 3 weeks later than in the other species. Secondly, in each species, the mean individual dry root weight of roots other than white roots is consistently higher than the mean individual dry root weight of white roots. Overall the three species and the whole experimental period, the average difference between these two root classes is of the order of 2 milligrams.

While realizing that these differences in individual root weights would be operating to favour Bn and penalize Bb, an analysis of variance on the dry weights of roots other than white roots per plant was calculated, and the results are presented in Table 13.

TABLE 13 Analysis of variance of dry weights of roots other than white roots per plant over all lifting dates.

Item	Sums of Squares	Degrees of freedom	Mean Square	F value	F required .05	F required .01	Result
Dates	6,443,400	10	644,340	1.09	2.35	3.37	N.S.
Species	140,095,900	2	70,047,950	118.12	3.49	5.85	**
Dates X Species	11,860,538	20	593,027	1.29	1.62	1.97	N.S.
Residual	100,132,639	217	461,441				
Total	258,532,477	249					

Mean dry weight ± std. error for Ba = 1384.8 ± 82.1
" " " " " " Bb = 931.8 ± 82.1
" " " " " " Bn = 2653.0 ± 82.1

$d_{.01}$ = 330

$d_{.05}$ = 242

The result of this analysis of variance shows that there is a difference between the species which is significant at the 1% level, but that the difference between dates, and the dates X species interaction, is non-significant. From the differences required for significance, it can be seen that the dry weight of roots other than white roots per plant in Bn is significantly greater than in Ba, while Ba is significantly greater than Bb. It thus appears that the differences between individual root weights in the three species are sufficiently great to mask differences in total dry root weights per plant, under these experimental conditions where only 8 plants of each species were lifted on each date.

(c) Number of roots other than white roots per tiller

These figures are derived from the numbers of tillers per plant, and the numbers of roots other than white roots per plant, and the calculated values for each plant of the three species over all liftings are presented in Appendix 2, while the mean value for each species at each lifting is shown in Figures 12, 13 and 14 for Ba, Bb and Bn respectively. On the view that it is the tiller and not the entire plant which is the essential unit in a pasture population (Mitchell, 1954), these derived figures should provide evidence as to the number of roots other than white roots which are available to sustain each tiller, and to differences which exist in this character between the three species under study. The value of such evidence is limited because the derived figure is only an average, and actual numbers of roots per tiller were, of course, not counted. There is likely to be some considerable variation between the amount of root tissue associated with an older and vigorously growing tiller than with a newly-formed tiller.

An analysis of variance for this data was calculated, and is set out in Table 14.

TABLE 14. Analysis of variance for number of roots other than white roots per tiller over all lifting dates.

Items	Sums of Squares	Degrees of freedom	Mean Square	F value	F required .05	F required .01	Result
Dates	234.2536	16	14.6408	5.24	1.97	2.62	**
Species	36.8391	2	18.4196	6.59	3.30	5.34	**
Dates X species	89.4445	32	2.7951	4.93	1.49	1.74	**
Residual	190.5191	336	0.5670				
Total	551.0563	386					

The result of this analysis of variance shows that there are highly significant (1% level) differences between the number of roots other

FIGURES 12, 13, 14.

The number and dry weight of roots other than white roots, and the number and dry weight of white roots, per tiller in perennial ryegrass, Italian ryegrass and tall fescue, respectively.

FIGURE 12. PERENNIAL RYEGRASS.

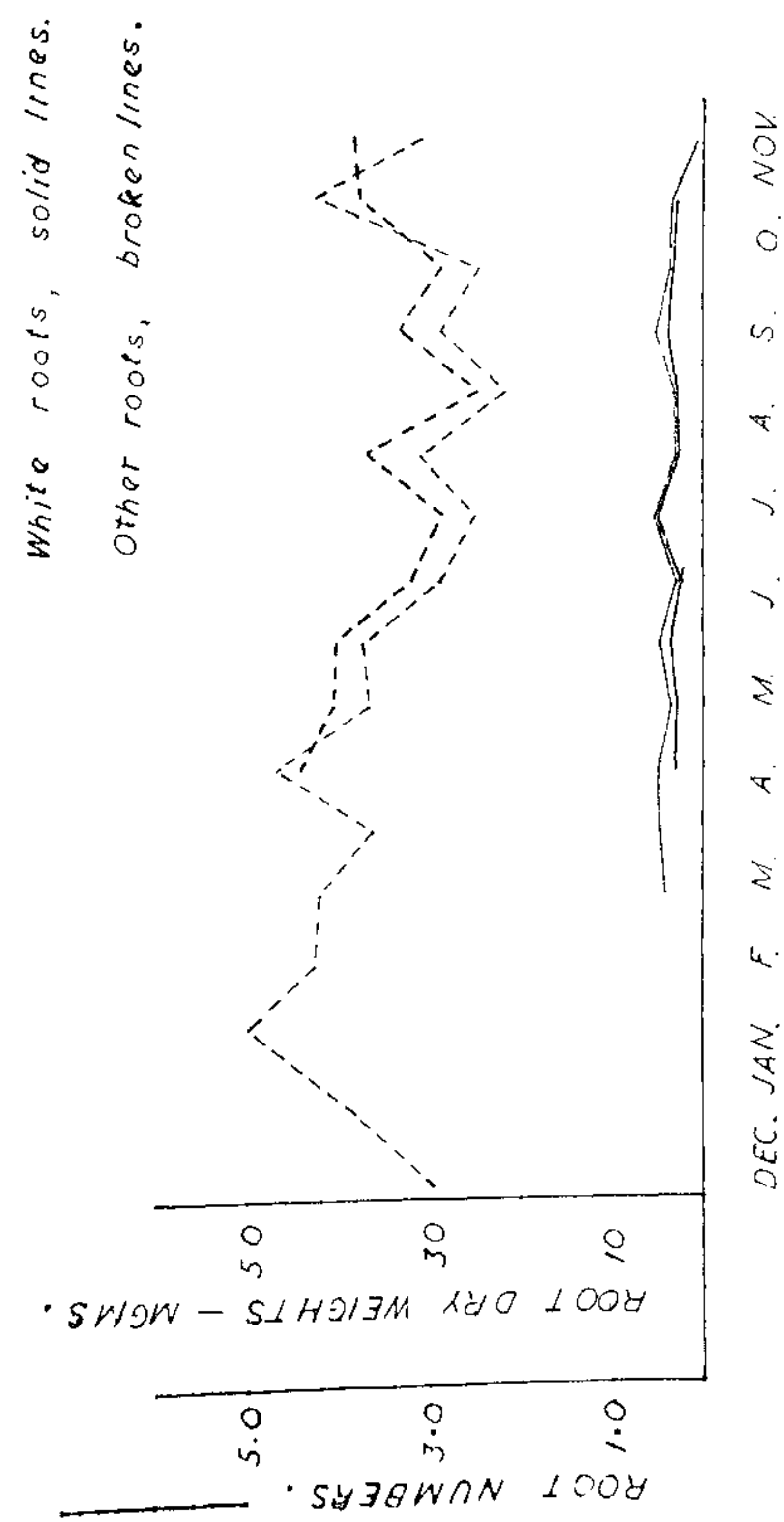
FIGURE 12.

FIGURE 13. ITALIAN RYEGRASS.

FIGURE 13.

FIGURE 14.

FIGURE 14. TALL FESCUE.



white roots per tiller between the various lifting dates and between the three species. Further, the highly significant dates X species interaction indicates the differences between the species altered over the course of the experiment. To examine these changes, an analysis of variance was calculated for each lifting date, and the relevant information is given in Table 15.

TABLE 15. Results of analyses of variance for number of roots other than white roots per tiller, at each separate lifting date.

Date	Means			Std. Errors		F values			Result	d required	
	Ba	Bb	Bn	Ba, Bn	Bb	Actual	.01	.05		.01	.05
4th December	2.48	3.43	2.97	± 0.31	± 0.31	2.30	5.78	3.47	N.S.	-	0.93
29th December	5.02	5.23	3.82	" 0.21	" 0.21	12.82	5.78	3.47	**	0.85	0.63
26th January	3.05	2.95	5.00	" 0.12	" 0.12	90.03	5.78	3.47	**	0.49	0.36
16th February	3.32	5.33	4.29	" 0.30	" 0.42	7.81	6.11	3.59	**	1.23	0.89
9th March	2.82	3.54	4.22	" 0.34	" 0.36	4.30	5.85	3.49	*	-	1.00
30th March	2.26	3.71	3.62	" 0.29	" 0.33	7.53	5.93	3.52	**	1.16	0.85
20th April	3.50	3.30	4.72	" 0.39	" 0.41	3.80	5.85	3.49	*	-	1.14
11th May	2.06	2.60	3.70	" 0.28	" 0.28	9.20	5.78	3.47	**	1.10	0.81
1st June	2.53	2.05	3.78	" 0.28	" 0.30	9.70	5.85	3.49	**	1.13	0.83
22nd June	2.06	1.70	2.92	" 0.23	" 0.23	7.45	5.78	3.47	**	0.92	0.68
13th July	2.03	1.45	2.52	" 0.13	" 0.16	13.44	6.01	3.55	**	0.52	0.38
3rd August	2.10	1.86	3.12	" 0.17	" 0.22	13.14	6.01	3.55	**	0.71	0.51
24th August	2.29	2.15	2.19	" 0.26	" 0.28	0.08	5.85	3.49	N.S.	-	0.75
14th September	2.49	2.04	2.89	" 0.24	" 0.28	2.73	5.93	3.52	N.S.	-	0.70
5th October	2.59	3.00	2.47	" 0.21	" 0.22	1.59	5.85	3.49	N.S.	-	0.62
27th October	3.72	3.64	4.28	" 0.36	" 0.38	0.90	5.85	3.49	N.S.	-	1.06
16th November	3.12	3.07	3.13	" 0.24	" 0.26	0.02	5.85	3.49	N.S.	-	0.72

From figures 12, 13 and 14, it can be seen that there is considerable variation in the values of this derived root character in each species. Despite this, some general trends are apparent. In Ba, the number of roots other than white roots per tiller is greater than 3 until the lifting on 9th March, at which date and until the 1st June, the number fluctuates rather widely about an approximate mean value of 2.5. For the next three liftings from the 22nd June until the 3rd August, the number of roots is a little more than 2 per tiller, and for the remaining liftings until the completion of the experiment, the number increases to a value of about 3.5. The period when the number is lowest coincides with the time when leaf growth is at its minimum during the winter, and tiller numbers are high. Many of the smaller tillers would probably be dependent on older tissues for at least part of their nutrition at this stage. The increase in the number of roots per tiller from the end of August coincides with the decline in tiller numbers as leaf growth starts to recover, and also with the ageing, and hence the re-classification of white roots formed during the winter. In Bb, the number of roots other than white roots per tiller remains well above 3 until the 20th April, and this covers the period during which there is a marked decline in tiller numbers. The associated decline in root numbers is of a lesser magnitude. The number of roots has dropped to about 2 per tiller by 1st June, and to approximately 1.5 by 13th July, a figure which is below the minimum recorded in Ba and is due to the low numbers of these roots per plant at this date, and to the fact that tiller numbers in this species are at their peak. There is a recovery to about 2 roots per tiller during August and early September, and the number increases to rather more than 3 from early October until completion of observations. This recovery from the latter part of July can be explained partly by the decrease in tiller numbers over this period, but mainly by the ageing of early-formed white roots, which became evident in large numbers from early May.

This is also general evidence that the period in autumn and early winter during which white roots retain their "white" characteristics, at least in Bb, is some 6-9 weeks. In Bn, the number of roots other than white roots per tiller remains at a high level above 3.5 until after the lifting on the 1st June, then falls to about 2.5 roots per tiller until the end of August, which in this species also is the period when tiller numbers are at their peak. The number of roots per tiller increases again from early September until the end of the trial. Since in Bn, the white root numbers are very steady from March onwards, and there is no great reduction of tiller numbers in the spring, it is not possible to assess the greater importance of either of these factors in this final increase of root numbers per tiller.

The results given in Table 15, show that on the 29th December, Bn has fewer roots other than white roots per tiller than either Ba or Bb at the 1% level of significance, but this is completely reversed on 26th January when Bn has significantly (1% level) more roots than Ba or Bb. On 16th February, Ba has less roots than Bb at the 1% level of significance, but at the 5% level, Ba has less than Bn which in turn has less than Bb. On 9th March, the only difference appears at the 5% level, where Ba has less roots than Bn. On 30th March, Ba has significantly fewer roots at the 1% level than either Bb or Bn. On 20th April, both Ba and Bb have fewer roots than Bn at the 5% level of significance, and this relation holds for both levels of significance at the liftings on 11th May and 1st June, and at the 5% level on 22nd June. On 22nd June, there is a difference between Bb and Bn at the 1% level, but not between Ba and Bn. On 13th July, Bb has significantly fewer roots than both Ba and Bn at the 1% level of significance, and at the 5% level, Ba has fewer roots than Bn. On 3rd August, both Ba and Bb have fewer roots per tiller than Bn at the 1% level, but from this date over the final five liftings of the experimental blocks, no statistically significant differences are present between any of the species.

In summary, three main periods can be recognized with numbers of roots other than white roots per tiller; (a) Up to the middle of March, results are too variable to show any regular trend. (b) From late March until the middle of August, Bm consistently has more roots per tiller than either ryegrass. (c) From late August, there are no differences between the species detectable on the data available. Two periods can be recognized where there is some difference between the ryegrasses: (a) Over the three liftings from 16th February to 30th March, when Bb has more roots per tiller than Ba. This can be explained by the decline in tiller numbers in Bb over this period, and the resultant inflation of root numbers when they are expressed on a per tiller basis. (b) From the lifting on 1st June until after that on 14th September, Bb consistently has fewer roots other than white roots per tiller than does Ba, although significance is not attained on some dates.

(d) Dry weight of roots other than white roots per tiller.

These figures are presented for individual plants at each lifting in Appendix 2, and the mean values for each species at each lifting date are shown in Figures 12, 13 and 14 for Ba, Bb and Bn respectively. These figures have been derived from a combination of numbers of tillers per plant and dry weight of roots other than white roots per plant, and may therefore show considerable variation since errors can be introduced with both sets of primary data. This particular root character also suffers from the already-discussed fact that the mean dry weights of individual roots are not the same in each species, but that individual Bn roots other than white roots are approximately double the dry weight of their Ba counterparts, and Bb roots in turn are rather heavier than those in Ba.

Despite these two factors operating to reduce the usefulness of the result, an analysis of variance was calculated for this data, and is presented in Table 16.

TABLE 16. Analysis of variance for dry weight of roots other than white roots per tiller over all lifting dates

Items	Sums of Squares	Degrees of freedom	Mean Square	F value	F required .05	F required .01	Result
Dates	2,071.08	10	207.108	1.34	2.35	3.37	N.S.
Species	28,035.70	2	14017.85	90.82	3.49	5.85	**
Dates X species	3,087.08	20	154.354	2.70	1.62	1.97	**
Residual	12,537.32	219	57.248				
Total	45,731.18	251					

In view of the highly significant dates X species interaction, further analyses of variance were carried out for each of the lifting dates, and the relevant results of these analyses are set out in Table 17.

TABLE 17. Results of analyses of variance for dry weight of roots other than white roots per tiller, at each separate lifting date.

Date	Means (mgm.)			Std. Errors		F values.			Result	d required	
	Ba	Bb	Bn	Ba,Bn	Bb	Actual	.01	.05		.01	.05
20th April	12.8	13.3	44.3	± 2.27	± 2.27	63.28	5.78	3.47	**	9.1	6.7
11th May	9.5	12.1	40.8	" 2.72	" 2.72	40.72	5.78	3.47	**	10.9	8.0
1st June	12.3	11.4	40.5	" 3.00	" 3.21	29.63	5.85	3.49	**	12.1	8.9
22nd June	10.0	9.5	32.1	" 1.76	" 1.76	53.69	5.78	3.47	**	7.1	5.2
13th July	11.8	8.5	28.7	" 1.46	" 1.84	49.02	6.01	3.55	**	5.9	4.3
3rd August	9.1	10.2	37.1	" 3.55	" 4.49	18.75	6.01	3.55	**	14.4	10.5
24th August	14.0	13.8	25.0	" 2.26	" 2.41	7.93	5.85	3.49	**	9.1	6.7
14th September	13.8	14.4	33.5	" 2.20	" 2.55	24.84	5.93	3.52	**	8.9	6.5
5th October	14.8	22.8	29.0	" 3.05	" 3.26	5.41	5.85	3.49	*	-	9.0
27th October	15.1	18.5	38.0	" 2.72	" 2.72	20.75	5.78	3.47	**	10.9	8.0
16th November	16.2	21.3	38.5	" 3.59	" 3.83	10.55	5.85	3.49	**	14.4	10.6

In Ba, the dry weight of roots other than white roots per tiller fluctuates about an average of some 11 milligrams until early in August, after which this weight increases and is a little over 15 milligrams on the completion of the experiment. In Bb, the dry weight of roots other than white roots per tiller decreases from some 13 milligrams in April to a minimum of 8.5 milligrams on 13th July, when tiller numbers have reached their peak. Thereafter, the weight increases, partly through a decrease in tiller numbers and partly because of ageing of white roots, and has reached a value of over 20 milligrams when the experiment ended in mid-November. In Bn, the weight of these roots per tiller decreases from more than 40 milligrams in April to some 25 milligrams during August, and then increases again to nearly 40 milligrams by the middle of November.

The results of the analyses of variance show that at all dates except the 5th October, Bn has a highly significant (1% level) greater dry weight of roots other than white roots per tiller, while at no date is there any significant difference at either level between Ba and Bb. On 5th October, a rather high weight for Bb and a low weight for Bn has caused loss of significance between these two species, and the only significant difference at this date is one at the 5% level between Ba and Bn, which has the greater weight. Thus in the case of dry weights of roots other than white roots per tiller, as on a per plant basis, the analysis of variance is not refined enough to determine differences between the two ryegrasses where only 8 plants of each species are involved at each lifting.

(c) Number of white roots per plant

White roots were first recorded as a separate class in each species at the 5th lifting on 9th March.

The number of white roots per individual plant of each of the three species is given in Appendix 2, while the mean values for each species at each lifting date are shown in Figures 8, 9 and 10 for Ba, Bb and Bn respectively. The analysis of variance calculated for this data is set out in Table 18.

TABLE 18. Analysis of variance for numbers of white roots per plant over all lifting dates.

Items	Sums of Squares	Degrees of freedom	Mean Square	F value	F required .05	F required .01	Result
Dates	124325.7	12	10360.5	3.89	2.18	3.03	**
Species	21163.3	2	10581.7	3.97	3.40	5.61	*
Dates X species	63950.2	24	2664.6	5.38	1.56	1.86	**
Residual	128876.5	260	495.7				
Total	338315.7	298					

This analysis of variance shows that there is a highly significant difference at the 1% level between the lifting dates, and a highly significant interaction between dates and species. There is a significant difference at the 5% level between the species. In view of the highly significant interaction between dates and species, analyses of variance were calculated for each lifting date, and relevant results are set out in Table 19.

TABLE 19. Results of analyses of variance for number of white roots per plant at each separate lifting date.

Date	Means			Std. Errors		F values				d required	
	Ba	Bb	Bn	Ba, Bn	Bb	Actual	.01	.05	Result	.01	.05
9th March	21.8	6.6	21.1	± 3.9	± 3.9	4.87	5.78	3.47	*	-	11.4
30th March	13.6	12.1	28.8	" 3.8	" 4.0	5.74	5.85	3.49	*	-	11.2
20th April	24.1	26.0	27.1	" 5.7	" 5.7	0.07	5.78	3.47	N.S.	-	16.9
11th May	48.1	35.3	26.5	" 7.1	" 7.1	1.88	5.78	3.47	N.S.	-	23.3
1st June	42.3	51.3	[illegible].4	" 6.3	" 6.7	1.89	5.85	3.49	N.S.	-	18.6
22nd June	43.0	52.1	[illegible]8.3	" 8.5	" 8.5	2.02	5.78	3.47	N.S.	-	24.9
13th July	64.6	127.4	5[illegible].3	"10.6	"13.4	10.45	6.01	3.55	**	43.1	31.4
3rd August	53.4	97.6	27.3	"12.9	"16.3	5.71	[illegible]	3.55	*	-	38.4
24th August	40.1	95.4	25.3	" 9.6	"10.2	13.75	5.85	3.49	**	38.4	28.2
14th September	26.5	68.5	39.5	"14.4	"15.4	0.62	5.93	3.52	N.S.	-	42.7
5th October	31.3	33.4	35.0	"18.5	"19.7	0.01	5.85	3.49	N.S.	-	54.5
27th October	12.4	9.5	27.1	" 3.0	" 3.0	9.79	5.78	3.47	**	12.1	8.9
16th November	4.1	8.4	4.4	" 1.5	" 1.6	2.46	5.85	3.49	N.S.	-	4.3

In Ba, the number of white roots per plant started with their first recognition on 9th March at 21.8, and was 13.6 on 30th March. During April and into May, there was an increase in white root numbers to between 40 and 50 per plant, and this level was maintained during the June liftings, before rising to a peak of 64 at the lifting on 13th July. From then on, there was a steady decrease in white root numbers per plant, with the exception of 5th October, which lifting showed a slight increase of 5 white roots over the preceding lifting. White roots were present in small numbers during the second half of October, and only 4 per plant were recorded at the final lifting in mid-November. In Bb, the number of white roots per plant was only 6.6 on 9th March, but increased steadily from that date, and reached a peak value of 127.4 white roots per plant on the 13th July. The value remained between 90 and 100 white roots during both the liftings in August, but thereafter declined steadily at each successive lifting and there were only 8.4 white roots per plant recorded on 16th November. In Bn, the number of white roots per plant was 21.1 at their first recognition on 9th March, but the numbers subsequently recorded in this species do not show steady increases and later decreases as found in the ryegrasses. Over 8 of the liftings, a mean value of between 20 and 30 white roots per plant was counted, and only 5 liftings gave values outside this range. These occurred on 1st June with 33.4; on 13th July with 52.3; on 14th September with 39.5 and the subsequent lifting on 5th October with 35.0; and on the final lifting on 16th November, when in common with the ryegrasses, the number of white roots had declined to very low levels (4.4 per plant for Bn.)

The results of the analyses of variance for each lifting date show that on 9th March, the number of white roots per Bb plant is significantly less at the 5% level than for either Ba or Bn. On 30th March, both Ba and Bb have significantly (5% level) fewer white roots than Bn. This evidence is important in the case of Bb, for the formation of new white roots at this stage lags behind Ba and Bn. It has already been shown that under these experimental conditions there is loss of both photosynthetic leaf tissue and of root tissue in Bb during February and March, which was not found in Ba or Bn. This latest evidence now shows that this same period is one when new root formation in Bb is later than in Ba or Bn in reaching appreciable levels, so that the autumn months are very critical in this species. Over the next four liftings from 20th April to 22nd June, there are no significant differences between the white root numbers per plant in the three species. On the 13th July, when white root numbers per plant are at their peak values in each species, Bb has a highly significant (1% level) greater number of white roots than Ba or Bn, and this relationship holds over the next two liftings on 3rd and 24th August, except that on 3rd August, significance is attained only at the 5% level. On 14th September and 5th October, there are no significant differences between the species, but on 27th October, Bn has a highly significant greater number of white roots per plant than Ba or Bb, due to rate of formation of white roots remaining at an appreciable level longer in Bn than in Ba or Bb. At the final lifting on 16th November, no significant differences in this character appeared.

Summarizing, there are three important trends shown by these analyses. Firstly, white root formation in Bb is slower to start than in Ba and Bn, and does not reach the higher levels until May. Secondly, white root formation in Bb is approximately double that in Ba, and 3 to 4 times that in Bn, during July and August. At this stage, therefore, there is more replacement of the root system occurring in Bb than in the other species. Thirdly, white root formation in Bn is at a fairly steady level from March until October, with a small increase in white root numbers during September, and with white root numbers remaining fairly high during October. This pattern contrasts with those in the ryegrasses, where increases to a peak in July was followed by decreases to low values by the end of October.

(f) Number of white roots per plant expressed as a percentage of the total number of roots per plant

Evidence given in the preceding section on numbers of white roots per plant strongly suggested that white roots were more prominent in the Bb root system than in those of Ba or Bn. It was thought that a satisfactory measure of this could be obtained by a comparison of each species, if the number of white roots recorded in each individual plant was expressed as a percentage of the total (white roots plus roots other than white roots) number of roots for that plant. The calculated percentages for each plant are given in Appendix 2, and the mean value for each species at each lifting is shown in Figure 15. An analysis of variance of this data was carried out, and is presented in Table 20. In the calculation of the analysis of variance, and in the discussion of these results, transformed data are used. The transformation is normal procedure where data is prepared as percentages, and is made by converting percentages into angles, where angle = $\arcsin \sqrt{\text{percentage}}$. The appropriate table for use in the conversions is given by Snedecor (1946, page 449-450).

TABLE 20. Analysis of variance for numbers of white roots per plant expressed as a percentage of the number of total roots per plant (transformed data) over all lifting dates.

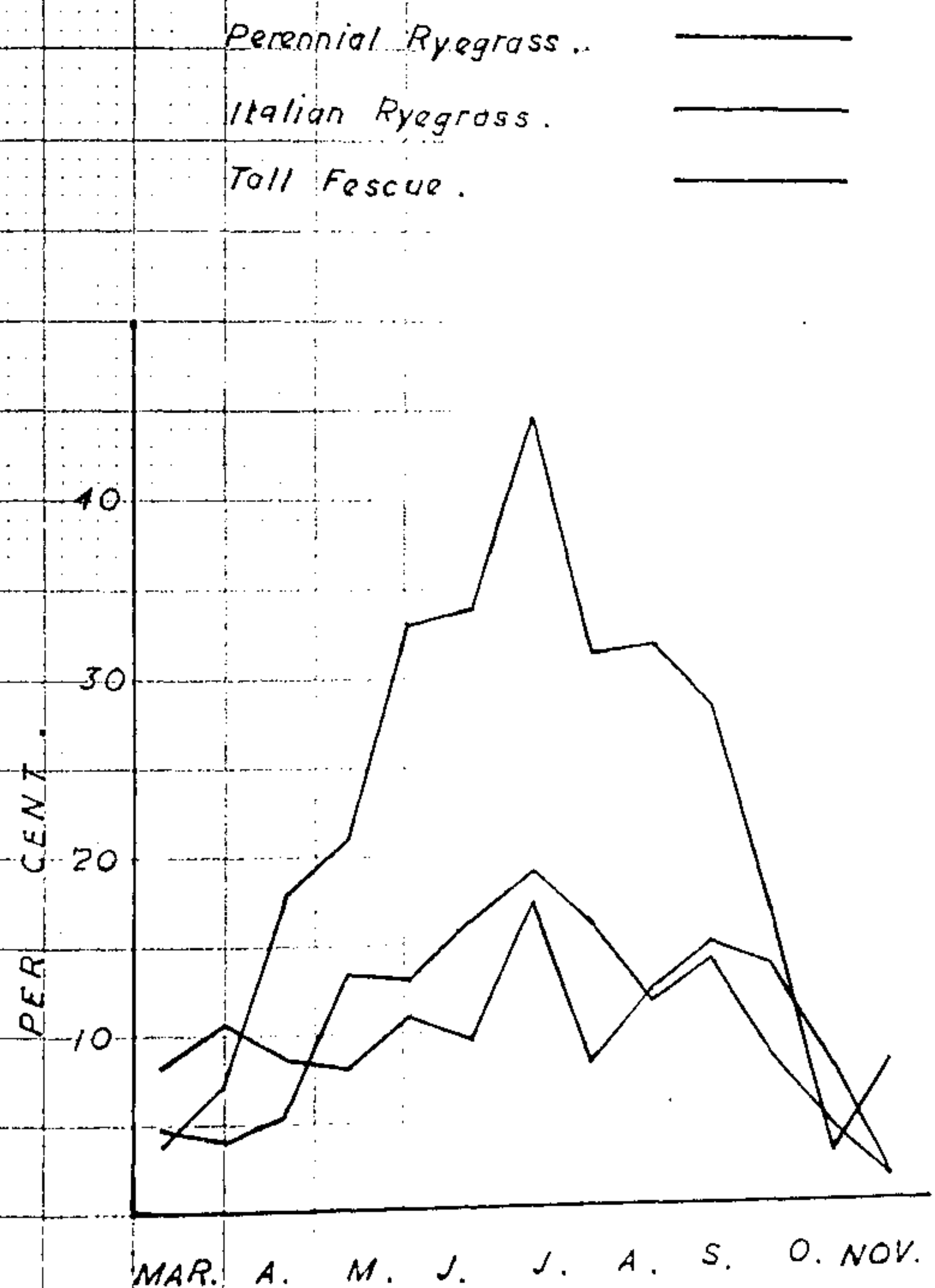
Items	Sums of Squares	Degrees of freedom	Mean Square	F value	F required .05	F required .01	Result
Dates	11025.26	12	918.77	5.68	2.18	3.03	**
Species	5239.64	2	2619.82	16.19	3.40	5.61	**
Dates X species	3883.78	24	161.82	6.04	1.56	1.87	**
Residual	6998.51	261	26.81				
Total	27147.19	299					

The analysis of variance shows that there is a highly significant difference (1% level) between both the dates and the species, while there is also a highly significant interaction between dates and species.

FIGURE 15.

The number of white roots per plant expressed as a percentage of the total number of roots per plant in perennial ryegrass, Italian ryegrass and tall fescue.

FIGURE 15.


Perennial Ryegrass ..
Italian Ryegrass .
Tall Fescue .
PER CENT.
40
30
20
10
MAR.
A.
M.
J.
J.
A.
S.
O.
NOV.

To determine the changes in the relationships between the species over the experimental period, which is implied by the interaction, analyses of variance were calculated for each separate lifting date. Results are set out in Table 21.

TABLE 21. Results of analyses of variance for numbers of white roots per plant expressed as a percentage of total number of roots per plant, (transformed data) for each separate lifting date.

Date	Means			Std. Errors		F values			Result	d required	
	Ba	Bb	Bn	Ba, Bn	Bb	Actual	.01	.05		.01	.05
9th March	12.7	11.4	16.7	± 1.6	± 1.6	2.82	5.78	3.47	N.S.	-	4.8
30th March	11.7	15.7	19.1	" 2.6	" 2.8	1.89	5.85	3.49	N.S.	-	8.0
20th April	13.9	25.1	17.2	" 1.7	" 1.7	11.52	5.78	3.47	**	6.7	5.0
11th May	21.5	27.3	16.5	" 2.3	" 2.3	5.76	5.78	3.47	*	-	6.6
1st June	21.2	35.1	19.4	" 1.3	" 1.4	38.71	5.85	3.49	**	5.3	3.9
22nd June	23.8	35.6	18.0	" 1.9	" 1.9	23.44	5.78	3.47	**	7.4	5.4
13th July	25.9	41.9	24.6	" 1.3	" 1.7	38.16	6.01	3.55	**	5.4	3.9
3rd August	23.7	34.1	16.6	" 2.3	" 2.9	11.06	6.01	3.55	**	9.4	6.8
24th August	20.0	34.4	20.4	" 1.6	" 1.7	25.26	5.85	3.49	**	6.3	4.6
14th September	22.0	32.3	22.8	" 1.8	" 1.8	9.16	5.78	3.47	**	7.6	5.6
5th October	17.0	24.2	21.7	" 2.0	" 2.2	3.11	5.85	3.49	N.S.	-	6.0
27th October	12.0	9.9	16.1	" 1.5	" 1.5	4.67	5.78	3.47	*	-	4.3
16th November	6.9	16.4	6.8	" 1.8	" 1.9	9.02	5.85	3.49	**	7.2	5.3

In Ba, the number of white roots as a percentage of the total roots, is about 13° up to the middle of April, and increases thereafter to 21° on 11th May and 1st June, and to the peak value of nearly 26° on 13th July. The angle then decreases, with the exception of the lifting on the 14th October when there is a small but unexplained increase, until the angle is at a minimum value of 6.9° when the experiment ends in mid-November. In Bb, the percentage of white roots in the total root system increases steadily from an angle of 11.4° on 9th March, to a peak value of 41.9° on 13th July. Thereafter, the angle declines until the end of the experiment, the increase in the angle on the 16th November being the result of the small root systems at that lifting. It should be noted here that for the liftings from 1st June until the 14th September inclusive, the value of the angle in Bb is more than 30°, which is not even approached at any single date by either Ba or Bn. In Bn, the percentage of the total root system made up of the white roots has an angular value between 15° and 20° until the 13th July. After this date, there is an increase to a little over 20° until the 5th October, and the angle then becomes smaller to a value of 6.8° by mid-November.

The results of the analyses of variance, as given in Table 21, show that for the two liftings in March, there are no significant differences between the species. On 20th April, Bb has a highly significant (1% level) greater percentage of white roots in the root system than does either Ba or Bn. On the 11th May, the angle for Ba has increased so that significance is lost in the differences between Ba and the other species, but there is a significant (5% level) difference between Bb (the greater) and Bn (the lesser). This difference just fails to achieve significance at the 1% level. From the 1st June to the 14th September inclusive, i.e. over 6 liftings, Bb has a highly significant (1% level) greater percentage of white roots than either Ba or Bn. On two dates within this period, 22nd June and 3rd August, a further difference appears in that Bn has a significantly lesser percentage of white roots in the total root system than has Ba at the 5% level. All significant differences have disappeared on 5th October. On 27th October, the slower decline in white root numbers in Bn has led to a significant difference at the 5% level, where Bb has a lower percentage of white roots than Bn. On the final lifting date of 16th November, the greater percentage of white roots in the very small root systems of Bb plants has again given highly significant differences in favour of Bb over Ba and Bn.

Summarizing, there are two important periods sorted out by the analyses in Table 21. Firstly are the two liftings during March, when the white root percentage in Bb is not significantly less than in Ba or Bn. Although it was found earlier that the actual number of white roots per plant in Bb over these dates was less than in Ba or Bn, the small size of the Bb root system during March has given comparable percentages in all species. Secondly, from the middle of April through until the middle of September, the percentage of white roots is significantly greater than in the other species.

(g) Dry weight of white roots per plant.

The dry weights of white roots in each individual plant are presented in Appendix 2, and the mean weights for each species at each lifting are shown in Figures 8, 9 and 10 for Ba, Bb and Bn respectively. An analysis of variance for this data is given in Table 22.

TABLE 22. Analysis of variance for dry weight of white roots per plant over all lifting dates.

Items	Sums of Squares	Degrees of freedom	Mean Square	F value	F required .05	F required .01	Result
Dates	1566486	9	174054	4.74	2.46	3.60	**
Species	968310	2	484155	13.18	3.55	6.01	**
Dates X species	661407	18	36745	1.94	1.66	2.03	*
Residual	3772899	199	18959				
Total	6969102	228					

This analysis of variance shows that there are highly significant (1% level) differences in the dry weight of white roots per plant between both the lifting dates and the species. There is also a significant (5% level) interaction between dates and species. Because of this interaction, analyses of variance were calculated for each lifting date, to elucidate the changes in the relationships between the species which took place over the experimental period. The relevant details of these analyses of variance are set out in Table 23.

TABLE 23. Results of analyses of variance for dry weights of white roots per plant for each separate lifting date.

Date	Means (Mgm.)			Std. Errors		F values			Result	d required	
	Ba	Bb	Bn	Ba, Bn	Bb	Actual	.01	.05		.01	.05
20th April	50	53	169	±29.0	±29.0	5.50	5.78	3.47	*	-	85
11th May	115	98	208	"39.0	"39.0	2.28	5.78	3.47	N.S.	-	115
1st June	121	165	258	"35.8	"38.3	3.81	5.85	3.49	*	-	106
22nd June	150	148	202	"39.5	"39.5	0.60	5.78	3.47	N.S.	-	116
13th July	196	401	514	"72.8	"92.0	4.86	6.01	3.55	*	-	216
3rd August	176	391	279	"79.1	"99.8	1.45	6.01	3.55	N.S.	-	234
24th August	120	328	256	"45.8	"48.9	5.05	5.85	3.49	*	-	135
14th September	103	249	299	"60.3	"69.7	2.83	5.93	3.52	N.S.	-	179
5th October	150	134	320	"40.0	"42.7	6.50	5.85	3.49	**	161	118
27th October	19	15	251	"25.0	"25.0	28.96	5.78	3.47	**	100	74

In Ba, the dry weight of white roots per plant increases from 50 milligrams on 20th April, when full dry weight records for every plant were first recorded, to nearly 200 milligrams at the peak weight on 13th July. Thereafter, the dry weight decreases, and with an unexplained increase in weight on 5th October, has fallen to about 20 milligrams of dry white root tissue per plant by the end of October. No analysis of variance could be carried out for the 16th November, since the numbers of white roots per plant on that date were so few that they were bulked for weighing in each species and only total weights became available. In Bb, the dry weight of white roots per plant increased from approximately 50 milligrams on 20th April, to a maximum of about 400 milligrams on the 13th July, although the dry weight recorded for Bb on the 22nd June was lower than expected. The dry weight remains at nearly 400 milligrams on 3rd August, and then decreases, but it is not until the lifting on 5th October that the dry weight of white roots in both Ba and Bb is again similar. In Bn, the dry weight of white roots per plant increased from about 170 milligrams on 20th April to over 200 milligrams from 11th May to 22nd June. On 13th July, there is a large sudden increase to over 500 milligrams per plant, and it is at this date that the number of white roots in Bn was approximately doubled. The dry weight then declines, and from the 3rd August over 5 liftings to the 27th October, the weight remains between 250 and 320 milligrams.

The results of the analyses of variance, as given in Table 23, show variable results. On 20th April there is a significant difference at the 5% level between Bn and Ba, Bb, with Bn having the greater dry weight of white roots per plant. No dignificant differences appeared on the 11th May, and this was repeated at subsequent alternate liftings on 22nd June, 3rd August, and 14th September. On 1st June, the only significant difference is between Ba (lesser) and Bn (greater) at the 5% level, and this relationship holds at the same level on 13th July. On 24th August, Ba has a significant (5% level) smaller dry weight of white roots per plant than both Bb and Bn. At the two October liftings, both Ba and Bb have a lesser weight than Bn, and this difference is highly significant at the 1% level.

In summary, two main points have emerged in this section. Firstly, the variations in the dry weights of white roots of individual plants are too great to allow a precision test with the analysis of variance on only 8 plants per species. This is similar to the position in dry weights of roots other than white roots per plant. It is the variations which account for the frequent loss of significance, even though the mean differences appear to be substantial. Secondly, although the dry weights of individual white roots in Bb are approximately only ½ of those in Bn, the greater number of white roots counted in Bb has meant that the dry weights of white roots per plant is of the same order in both these species from the 13th July until the 14th September.

(h) Dry weight of white roots per plant expressed as a percentage of the total dry weight of roots per plant.

In view of the evidence on the relatively greater proportion of white roots in the root system in Bb which became available from the analysis carried out on numbers of white roots and all roots, a similar analysis is warranted from the dry weights of white roots and the whole root system. Despite the variation in the dry weights of roots, the reduction of the weights of white roots to a percentage figure of the weights of all roots may allow a rather better standard of precision in the analysis. Further, since all weights are on a percentage basis, the fact that the weights of individual roots in Bn are so much heavier than in Ba and Bb becomes of no importance in this analysis.

The percentage dry weights of white roots per plant of the total root system are given for each species in Appendix 2, and mean values for each species at each lifting are shown in Figure 16. In the analysis of variance for this data, (Table 24), the percentages have again been transformed into angles, and these angular values are retained in the analyses of variance at each lifting date, and in the discussion of these results.

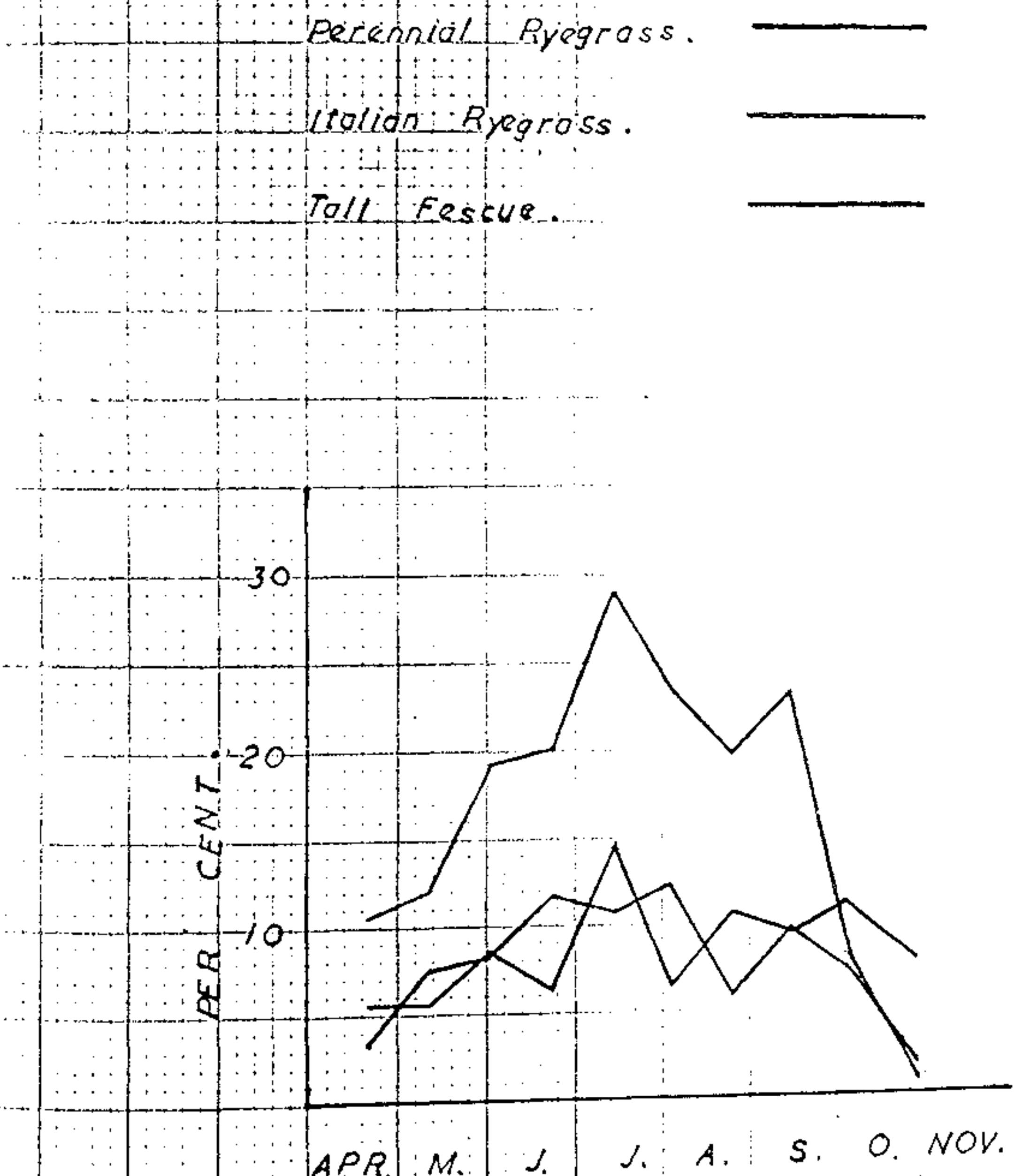
TABLE 24. Analysis of variance for dry weights of white roots per plant expressed as a percentage of the dry weight of total roots per plant (transformed data) over all lifting dates.

Items	Sums of Squares	Degrees of freedom	Mean Square	F value	F required .05	F required .01	Result
Dates	3902.18	9	433.58	3.17	2.46	3.60	*
Species	2445.11	2	1222.55	8.95	3.55	6.01	**
Dates X species	2459.92	18	136.66	5.41	1.65	2.03	**
Residual	5002.54	198	25.27				
Total	13809.75	227					

FIGURE 16.

The dry weight of white roots per plant expressed as a percentage of the total dry weight of roots per plant in perennial ryegrass, Italian ryegrass, and tall fescue.

FIGURE 16.



Perennial Ryegrass.
Italian Ryegrass.
Tall Fescue.
30
20
10
PER CENT.
APR.
M.
J.
J.
A.
S.
O.
NOV.

This analysis of variance shows that there is a significant difference at the 5% level between the percentage dry weights of white roots in the dry weights of the total root system at different lifting dates, and a highly significant difference at the 1% level between the three species. There is also a highly significant dates-species interaction, so that analyses of variance were calculated for each lifting date, and the relevant results are given in Table 25.

TABLE 25. Results of analyses of variance for dry weights of white roots per plant expressed as a percentage of the dry weights of the entire root systems per plant (transformed data) for each separate lifting date.

	Means			Std. Errors		F values				d required	
Date	Ba	Bb	Bn	Ba, Bn	Bb	Actual	.01	.05	Result	.01	.05
20th April	10.4	18.8	13.6	± 1.9	± 1.9	4.75	5.78	3.47	*	-	5.7
11th May	15.8	20.3	13.7	" 2.2	" 2.2	2.45	5.78	3.47	N.S.	-	6.4
1st June	16.6	26.0	16.7	" 1.5	" 1.7	11.08	5.93	3.52	**	5.9	4.3
22nd June	19.9	26.6	14.5	" 1.9	" 1.9	10.07	5.78	3.47	**	7.6	5.6
13th July	19.2	32.5	22.5	" 1.4	" 1.7	19.13	6.01	3.55	**	5.5	4.0
3rd August	20.5	28.9	14.7	" 2.4	" 3.1	6.70	6.01	3.55	**	9.9	7.2
24th August	14.1	26.5	19.0	" 1.6	" 1.7	14.68	5.85	3.49	**	6.3	4.6
14th September	18.1	28.7	17.9	" 1.7	" 2.0	10.71	5.93	3.52	**	6.9	5.0
5th October	15.5	16.4	19.5	" 1.8	" 1.9	1.39	5.85	3.49	N.S.	-	5.2
27th October	7.7	5.5	16.2	" 1.1	" 1.1	24.48	5.78	3.47	**	4.6	3.3

In Ba, the angular value corresponding to the white roots dry weight percentage of the dry weight of all roots increases from 10.4° on 20th April, to nearly 20° on 22nd June and 13th July, and to the peak value of 20.5° on 3rd August. The angle decreases after this date to about 15° by the 5th October, and at the last lifting when white root weights were recorded for individual plants on the 27th October, the angle had declined to just under 8°. In Bb, the angle is nearly 19° on 20th April, increases over the next few liftings to reach its peak value of 32.5° on 13th July, and declines from then on, until the final value recorded is 5.5° on 27th October. The angular value in Bb is greater than 25° for the liftings from 1st June until 14th September respectively, and this value of 25° is not even approached at any date in Ba and Bn. This period from beginning of June to the middle of September is the same as that in which Bb showed a greater percentage of white roots in the total root system as calculated on numbers. In Bn, the angle is a little under 14° on 20th April and 11th May, and then increases to the maximum value of 22.5° on 13th July, although there is an unexpectedly low figure for 22nd June. The angle on 3rd August is also unduly low, and for the liftings on 24th August until the 27th October, the angle remains between 20° and 16°.

The results of the analyses of variance given in Table 25 show that on the 20th April, Ba has a lower percentage than Bb, significant at the 5% level. On 11th May, there are no significant differences. On 1st June, Bb has a highly significant (1% level) greater percentage than Ba or Bn. On 22nd June, Bb has a highly significant (1% level) greater percentage than Bn, and a significantly (5% level) greater percentage than Ba or Bn. On 13th July, Bb has a highly significant (1% level) greater percentage than Ba or Bn. On 3rd August, Bb has a highly significant (1% level) greater percentage than Bn, and a significantly (5% level) greater percentage than Ba and Bn. On 24th August, Bb has a highly significant (1% level) greater percentage than Ba and Bn, while on this same date at the 5% level, Bn also has a significantly greater percentage than Ba. On 14th September, Bb retains a highly significant (1% level) greater percentage than Ba or Bn. There are no significant differences on 5th October, and on 27th October, the retention of a higher level of white root formation in Bn compared to the ryegrasses has given a highly significant (1% level) greater percentage in Bn than in Ba or Bb.

Summarizing, the main point in this analysis is that the pattern of percentages based on dry weights of white roots and all roots is essentially the same as the pattern obtained when percentages were based on number. From the 1st June until the 14th September inclusive, the percentage dry weight of white roots in the dry weights of the whole root system per plant, is significantly greater than in either Ba or Bn. However, the precision of these significant differences is not as great on a dry weight basis as on a number basis. This is seen in the failure of the differences to be highly significant at the 1% level on certain dates, and can also be deduced from a comparison of figures 15 and 16. The failure of the percentages based on dry weights to reach the same high levels as those based on numbers can be explained by the lower dry weights of individual white roots in comparison with the dry weights of individual roots other than white roots, in all 3 species. This is clearly shown in figure 11. The result is to depress the percentages based on dry weight below those based on number, and to increase the chances that percentages based on dry weights may fail to show significant differences between the species.

(i) Number of white roots per tiller.

It has already been established that the 3 species under study exhibit different patterns in the number of tillers per plant, and in the number of white roots per plant, over the experimental period. A combination of these two counts to give the number of white roots per tiller, may therefore show the importance of newly formed roots to the essential components in a pasture population, which are the individual tillers. It is realized that newly formed tillers will possess more white roots than older tillers, but the experiment was designed only to study plants as a whole, and not tillers by themselves. It was observed, however, that white roots tended to be more numerous around the periphery of the root system, and that new tillers were more numerous around the periphery of the plant. In view of the fact that white root numbers per plant (figures 8, 9 and 10) did not coincide directly with the increases in numbers of tillers per plant (figures 2, 3 and 4), it appears that new root formation was taking place on some of the older tillers. Although these factors are present and cannot be fully assessed, it is likely that an analysis of the number of white roots per tiller within each individual plant will indicate the importance or otherwise of new root formation.

The numbers of white roots per tiller for individual plants are given in Appendix 2, and the mean number of white roots per tiller for each species at each lifting are shown in Figures 12, 13 and 14 for Ba, Bb and Bn respectively. An analysis of variance for this data is given in Table 26.

TABLE 26. Analysis of variance for numbers of white roots per tiller over all lifting dates.

Items	Sums of Squares	Degrees of freedom	Mean Square	F value	F required .05	F required .01	Result
Dates	8.0186	12	0.6882	3.20	2.18	3.03	**
Species	9.8446	2	4.9223	23.60	3.40	5.61	**
Dates X species	5.0057	24	0.2086	4.78	1.56	1.87	**
Residual	11.2603	258	0.0436				
Total	34.1292	296					

The analysis of variance shows that there are highly significant (1% level) differences between both dates and species, and that there is a highly significant interaction between dates and species. To elucidate this interaction, separate analyses of variance for each lifting date were calculated and relevant results are presented in Table 27.

TABLE 27. Results of analyses of variance for number of white roots per tiller, for each separate lifting date.

Date	Means			Std. Errors		F values			Result	d required	
	Ba	Bb	Bn	Ba, Bn	Bb	Actual	.01	.05		.01	.05
9th March	0.15	0.21	0.41	± 0.06	± 0.06	4.83	5.78	3.47	*	-	0.18
30th March	0.10	0.50	0.47	" 0.10	" 0.11	5.15	5.93	3.52	*	-	0.28
20th April	0.22	0.79	0.47	" 0.11	" 0.11	6.89	5.78	3.47	**	0.44	0.32
11th May	0.32	0.65	0.37	" 0.07	" 0.07	6.81	5.78	3.47	**	0.27	0.20
1st June	0.39	0.97	0.46	" 0.07	" 0.08	17.21	5.93	3.52	**	0.28	0.21
22nd June	0.40	0.82	0.30	" 0.06	" 0.06	20.22	5.78	3.47	**	0.24	0.18
13th July	0.48	1.11	0.53	" 0.04	" 0.05	56.12	6.01	3.55	**	0.16	0.12
3rd August	0.40	0.88	0.30	" 0.08	" 0.10	10.86	6.01	3.55	**	0.32	0.24
24th August	0.32	1.00	0.32	" 0.10	" 0.10	15.52	5.85	3.49	**	0.39	0.28
14th September	0.36	1.02	0.51	" 0.07	" 0.08	19.42	5.93	3.52	**	0.29	0.21
5th October	0.27	0.63	0.39	" 0.08	" 0.09	4.48	5.85	3.49	*	-	0.24
27th October	0.19	0.13	0.36	" 0.05	" 0.05	6.79	5.78	3.47	**	0.18	0.13
16th November	0.05	0.30	0.06	" 0.04	" 0.04	14.77	5.85	3.49	**	0.14	0.10

In Ba, the number of white roots per tiller increases from some 0.10 during March to a maximum value of 0.48 on 13th July, and decreases fairly regularly to 0.05 on 16th November. Within this overall pattern, there were more than 0.30 white roots per tiller in Ba from the lifting on 11th May until the lifting on 5th October. In Bb, the value of 0.21 on 9th March increased rapidly to approximately 0.75 during late April and early May, and then increased still further to the maximum value of 1.11 by 13th July. The number remained of the order of 1 white root per tiller until after the lifting on 14th September, when a rapid decrease of nearly 0.5 white roots occurred at each of the next two liftings. The increase in the value to 0.30 at the final lifting on 16th November was due to the small size of the Bb plants in that particular block. In Bb, the number of white roots per tiller is greater than 0.5 from 30th March to 5th October inclusive, and is greater than 0.8 from 1st June to 14th September inclusive. In Bn, the pattern does not show the typical rise and fall in values as is the case in the rye-grasses. In Bn, the number of white roots per tiller is between 0.4 and 0.5 from the 9th March to the 1st June inclusive (with the exception of 0.37 on 11th May), and is between 0.3 and 0.4 from 22nd June until 27th October inclusive (with the exceptions of 0.53 on 13th July and 0.51 on 14th September).

The results of the analyses of variance given in Table 27 show that on the 9th March, Bn has a significantly (5% level) greater number of white roots per tiller than Ba or Bb. On 30th March, the increase in white root numbers per tiller in Bb has led to loss of a significant difference between Bb and Bn, but both these species have a significantly (5% level) higher figure than Ba. On 20th April, Bb has a highly significant (1% level) greater value than Ba, while at the 5% level, Bb has a greater value than Ba and Bn. For the seven liftings from 11th May to 14th September inclusive, Bb has a highly significant (1% level) greater number of white roots per tiller than Ba or Bn. On 5th October, this same relationship holds, but is significant at only the 5% level. On 27th October, the retention of more white roots in Bn compared with the ryegrasses has led to Bn having highly significant (1% level) more white roots per tiller than Bb, and significantly more (5% level) than Ba or Bb. At the final lifting on 16th November, the increase in white roots per tiller in Bb, due to the small root systems in this species, has given Bb highly significant (1% level) more roots than Ba or Bn, although the actual number of white roots per plant shows a decrease at this date in all three species.

Summarizing, two main points in this data have emerged. Firstly is the fact that the number of white roots per tiller in Bb is at a consistently higher level than in Ba or Bn from early April until the middle of October. This is evidence that although many of the white roots will be associated with newly-formed tillers, there is a replacement of older roots in Bb occurring at a greater level of activity than in Ba or Bn. This conclusion is supported by the means given in Table 15, which show that the number of roots other than white roots per tiller is lower in Bb than in the other species from 1st June until the 14th September inclusive. Secondly, the pattern in Bn, where the number of white roots per tiller is comparatively constant, parallels the pattern for this species in number of white roots per plant. The small decrease in values which occurred in Bn after 1st June can be explained by the increase in tiller numbers in Bn from May onwards.

(j) Dry weight of white roots per tiller

This data was examined to determine whether or not similar conclusions to those drawn from the number of white roots per tiller could be obtained when the dry weight of white roots per tiller was considered. Values for individual plants are given in Appendix 2, and the mean weights for each species at each lifting are shown in Figures 12, 13 and 14 for Ba, Bb and Bn respectively. An analysis of variance of this data is presented in Table 28.

TABLE 28. Analysis of variance for dry weights of white roots per tiller over all lifting dates.

Items	Sums of Squares	Degrees of freedom	Mean Square	F value	F required .05	F required .01	Result
Dates	83.38	9	9.26	2.90	2.46	3.60	*
Species	217.26	2	108.63	34.05	3.55	6.01	**
Dates X species	57.38	18	3.19	1.65	1.65	2.03	*
Residual	385.45	199	1.93				
Total	743.47	228					

This analysis of variance shows that there is a significant (5% level) difference between dates, and a highly significant (1% level) difference between the species. There is also an interaction between dates and species which just attains significance at the 5% level. To elucidate this interaction, analyses of variance were calculated for the separate lifting dates, and the relevant results are presented in Table 29.

TABLE 29. Results of analyses of variance for dry weights of white roots per tiller for each separate lifting date.

Dates	Means (mgms.)			Std. Errors		F values			Result	d required	
	Ba	Bb	Bn	Ba, Bn	Bb	Actual	.01	.05		.01	.05
20th April	0.5	1.7	2.9	± 0.50	± 0.50	6.13	5.78	3.47	**	2.0	1.5
11th May	0.7	1.7	2.8	" 0.45	" 0.45	5.55	5.78	3.47	*	-	1.3
1st June	1.1	3.0	3.6	" 0.40	" 0.46	10.47	5.93	3.52	**	1.6	1.2
22nd June	1.4	2.3	2.1	" 0.32	" 0.32	3.16	5.78	3.47	N.S.	-	0.9
13th July	1.4	3.2	5.1	" 0.47	" 0.60	14.88	6.01	3.55	**	1.9	1.4
3rd August	1.4	3.5	3.0	" 0.67	" 0.84	2.41	6.01	3.55	N.S.	-	2.0
24th August	0.9	3.4	3.1	" 0.47	" 0.50	7.58	5.85	3.49	**	1.9	1.4
14th September	1.4	3.6	3.9	" 0.71	" 0.71	3.85	5.78	3.47	*	-	2.1
5th October	1.3	2.4	3.7	" 0.50	" 0.54	5.68	5.85	3.49	*	-	1.5
27th October	0.3	0.2	3.2	" 0.28	" 0.30	35.23	5.85	3.49	**	1.1	0.8

In Ba, the dry weight of white roots per tiller increased from 0.5 milligrams on 20th April to 1.4 milligrams by 22nd June, and remained at this value until after the 14th September, the only exception during these 5 liftings being an unexplained decline to 0.9 milligrams on 24th August. There was a very slight drop to 1.3 milligrams on 5th October, and a marked drop to 0.3 milligrams on 27th October. In Bb, the dry weight of white roots per tiller increased from 1.7 milligrams on both 20th April and 11th May to 3.5 milligrams on 3rd August after an unexplained decline to 2.3 milligrams on 22nd June. This value of approximately 3½ milligrams was maintained until after the 14th September, and the weight decreased markedly during October. In Bn, the dry weight of white roots per tiller was nearly 3 milligrams until the middle of May, and from then on with the sole exception of the lifting on 22nd June, the values remained above 3 milligrams. The peak value of 5.1 milligrams on 13th July was a reflection of the sudden substantial but not sustained increase found on that date in both numbers and dry weights of white roots per plant in this species. There is a secondary peak in Bn on the 14th September and 5th October, when the weights approach 4 milligrams per tiller.

The analyses of variance given in Table 29 show that on 20th April, Bn has a highly significant (1% level) greater dry weight of white roots per tiller than Ba. This same difference holds on 11th May, but is significant at only the 5% level. On 1st June, both Bb and Bn have a highly significant (1% level) greater value than Ba. On 22nd June, there are no significant differences. On 13th July, Bn (due to the sudden increase to 5.1 milligrams white root per tiller) is highly significantly (1% level) greater than Ba or Bb, while on the same date but at the 5% level of significance, Bb has a greater weight than Ba. There are no significant differences on 3rd August. On 24th August, both Bb and Bn have a highly significant (1% level) greater value than Ba. On 14th September, Bb and Bn have a significant (5% level) greater value than Ba. The only difference on the 5th October is at the 5% level of significance between Bn (greater) and Ba (lesser). On 27th October, Bn has a highly significant (1% level) greater weight than Ba or Bb.

In summary, two points should be noted. Firstly, the small weights of dry white root tissue per tiller have led to loss of precision in the analysis, and this is indicated by the high standard errors given in Table 29, and by the loss of significance, or significance being found only at the 5% level for these analyses of variance at separate lifting dates. In this case, as has already been noted in earlier examples, analyses based on dry weights are not so penetrating as those based on number, because of the greater variation which occurred in the dry weight data compared to the numbers data. Secondly, although the dry weight of the individual white root in Bn is about three times that of the individual Bb white root, the greater number of white roots in Bb has led to dry weights of white root tissue of similar values in Bb and Bn from early June until the middle of September. At no time did the dry weight of white roots per tiller in Ba reach half the values recorded in Bb and Bn.

D. Relationships Between Roots and Leaf Yields.

An examination of the leaf yields shown in figures 2, 3 and 4, and of the numbers of white roots per plant shown in figures 8, 9 and 10, for Ba, Bb and Bn respectively, indicates that there may be a negative correlation between these two characters. To test this assumption, correlation coefficients were calculated for each species for the dry weight of leaf per plant per day, and the number of white roots per plant. The dates of the leaf cuts did not coincide with the dates on which blocks were lifted for root measurements, so that for the purposes of the calculation, one or other of the characters under consideration had to be interpolated. It was decided to use the lifting dates, and hence the number of white roots per plant as these were actually counted, while the interpolations for these same dates were made from the dry leaf yield per plant per day curves in figures 2, 3 and 4. It was further decided to use the interpolated leaf yield figures and the numbers of white roots per plant without any smoothing of irregularities, since these values represent the best estimates available for these characters at any given date.

Results of the calculations of the correlation coefficients are reported in Table 30, and the scatter diagrams for this data are shown in figure 17. The period covered by the calculation is from 9th March to 5th October inclusive.

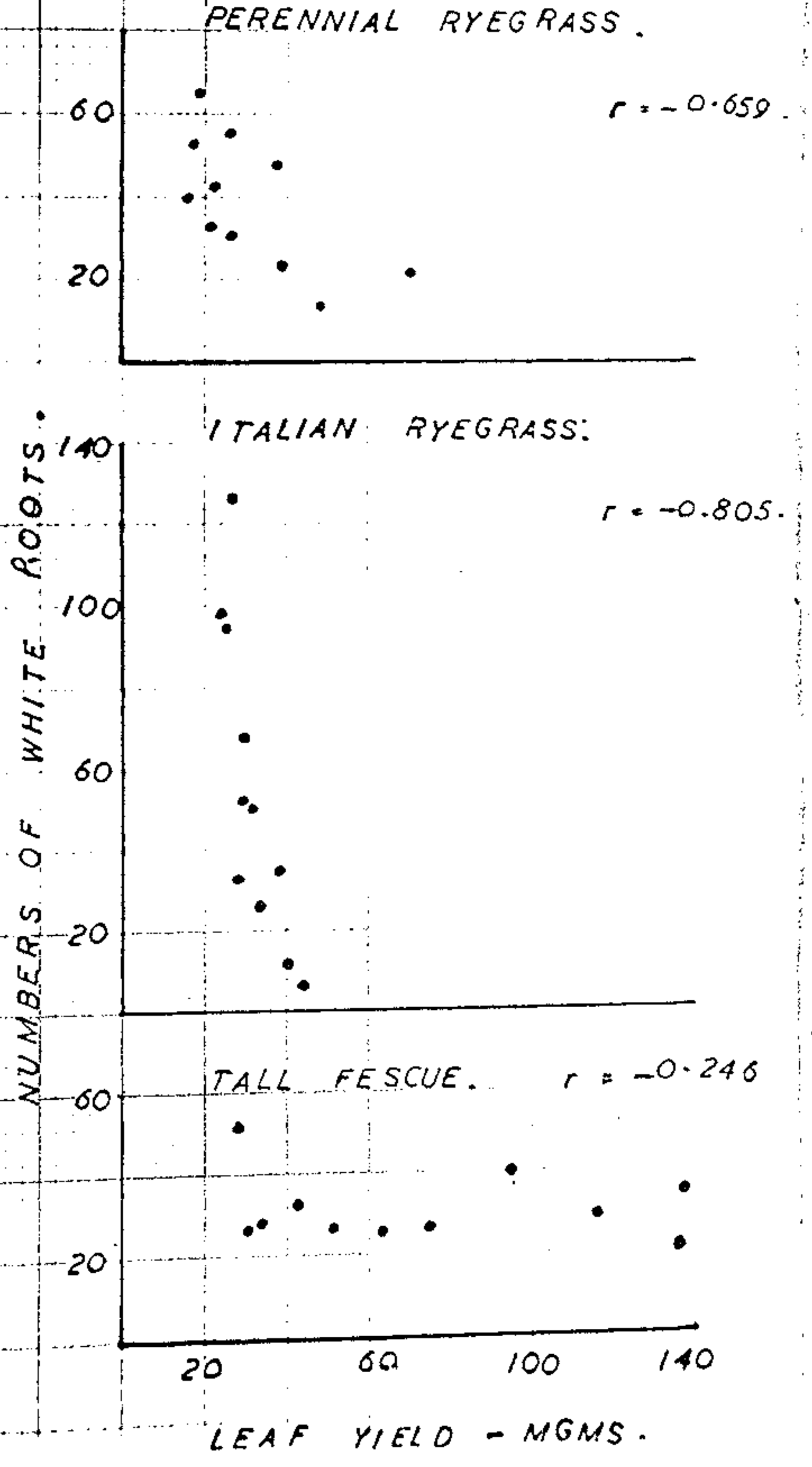
<u>TABLE 30.</u> <u>Correlation coefficients between numbers of white roots per plant, and the interpolated dry weights of leafage per plant per day for the same dates.</u>

	Values of r.			Result of test
	Actual	Required at 5% level	Required at 1% level	
Perennial ryegrass	- 0.659	0.602	0.735	*
Italian ryegrass	- 0.805	0.602	0.735	**
Tall fescue	- 0.246	0.602	0.735	N.S.

FIGURE 17.

Scatter diagrams for mean numbers of white roots per plant, and the interpolated dry weight of leafage per plant per day for the same dates, in perennial ryegrass, Italian ryegrass and tall fescue.

FIGURE 17.


PERENNIAL RYEGRASS.
r = -0.659.
60
20
ITALIAN RYEGRASS.
r = -0.805.
140
100
60
20
TALL FESCUE.
r = -0.246
60
20
NUMBERS OF WHITE ROOTS.
20
60
100
140
LEAF YIELD - MGMS.

The correlation coefficients show that in Ba, there is a negative correlation, significant at the 5% level, between dry weight of leafage per plant per day, and the number of white roots per plant. The conclusion is that during the period from early March until early October, white root numbers are increasing as herbage yield is declining, and white root numbers are later falling away as herbage yield is increasing towards the end of this period. In other words, the time of maximum leaf growth does not coincide with the time of maximum root initiation in this species. In Bb, the negative correlation between dry weight of leafage per plant per day and the number of white roots per plant is highly significant at the 1% level. In this species, therefore, the same conclusion can be drawn as in the case of Ba. The higher correlation coefficient in Bb can be explained on the overall greater number of white roots per plant, and the pronounced peak in white root numbers per plant from the middle of July until the end of August, corresponding to the trough of leaf production. In Bn, the failure of the correlation coefficient to attain significance is due to the fact that white root numbers were at a steady level during the entire period covered by the calculation, while leaf yield was declining until July and increased rapidly again during August and September.

In order to determine whether or not the same conclusions could be drawn when dry weights of white roots per plant were considered instead of white root numbers, a further series of correlation coefficients were calculated. Results are set out in Table 31, and the scatter diagrams for each species are given in figure 18.

FIGURE 18.

Scatter diagrams for mean dry weight of white roots per plant, and the interpolated dry weights of leafage per plant per day for the same dates, in perennial ryegrass, Italian ryegrass and tall fescue.

FIGURE 18.

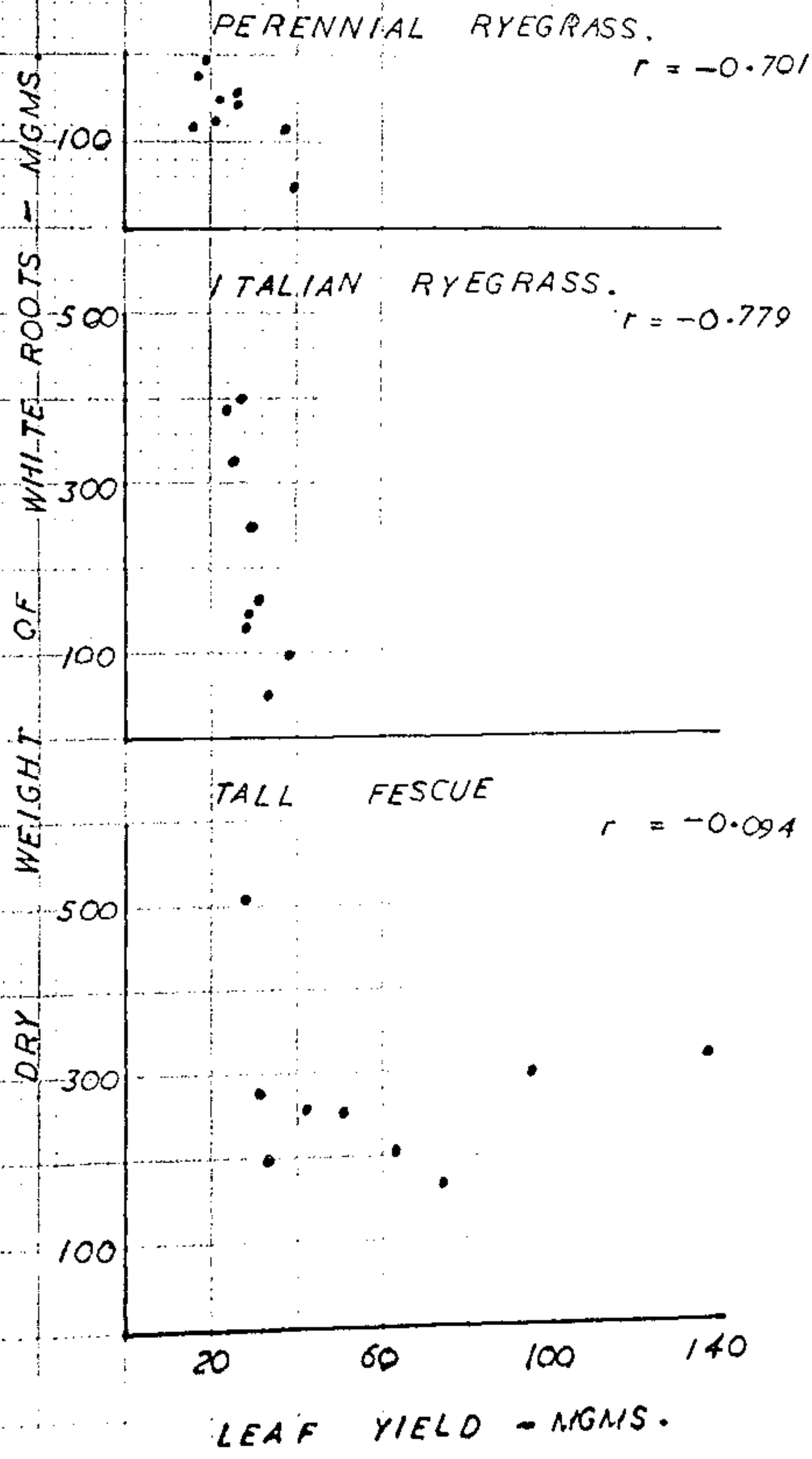

PERENNIAL RYEGRASS.
r = −0·701
ITALIAN RYEGRASS.
r = −0·779
TALL FESCUE
r = −0·094
DRY WEIGHT OF WHITE ROOTS - MGMS.
100
500
300
100
500
300
100
20
60
100
140
LEAF YIELD - MGMS.

TABLE 31. Correlation coefficients between dry weights of white roots per plant, and the interpolated dry weights of leafage per plant per day for the same dates.

Species	Values of r: Actual	Required at 5% level	Required at 1% level	Result of test
Perennial ryegrass	- 0.701	0.666	0.798	*
Italian ryegrass	- 0.779	0.666	0.798	*
Tall fescue	- 0.094	0.666	0.798	N.S.

The calculations leading to Table 31 cover the period 20th April to 5th October inclusive. This reduction in the number of pairs of data, sets higher values of r which must be attained for significance at the 5% and 1% levels. In Ba, the calculated value of r has increased, and significance remains at about the same level (approximately 3%), but in Bb, the calculated value of r has decreased a little, and significance now fails to reach the 1% level. The calculated value of r in Bn is very low.

The same conclusions that were drawn from the correlation coefficients based on white root numbers, can be drawn from these correlation coefficients based on the dry weight of white roots per plant. In both the ryegrass species the significant negative correlation implies that the periods of maximum leaf yield and maximum white root weights do not coincide. In tall fescue there is no correlation between leaf yield and white root weights.

Correlation coefficients were also calculated between both numbers and dry weights of roots other than white roots per plant, and dry weight of leafage per plant per day. Results are given in Table 32 and figure 19 for the calculations based on root numbers, and in Table 33 and figure 20 for those based on root dry weights.

FIGURES 19, and 20.

Scatter diagrams for mean numbers of roots other than white roots per plant, and for mean dry weight of roots other than white roots per plant, respectively, and the interpolated dry weights of leafage per plant per day for the same dates in perennial ryegrass, Italian ryegrass and tall fescue.

FIGURE 19.

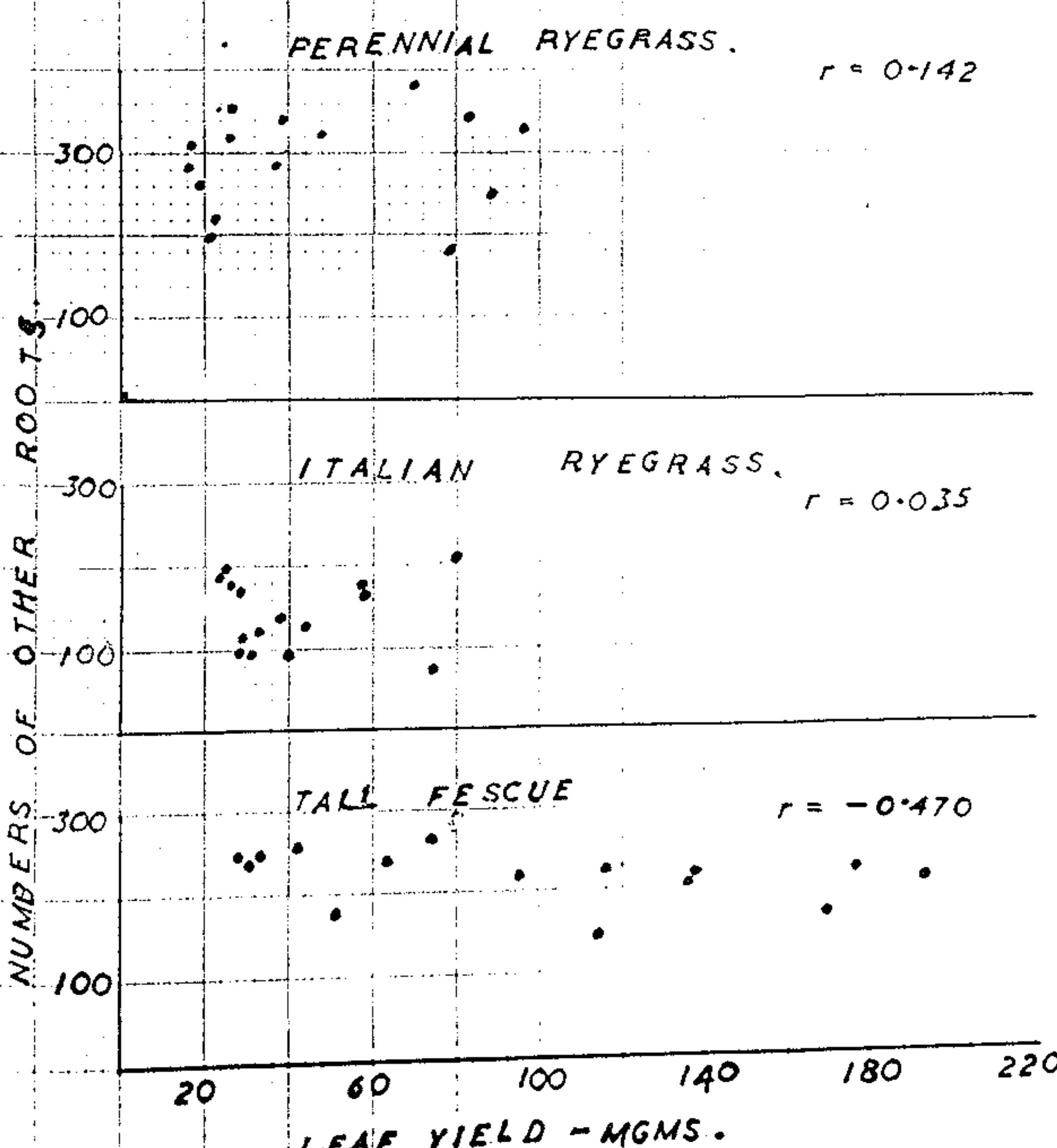

PERENNIAL RYEGRASS.
r = 0·142
ITALIAN RYEGRASS.
r = 0·035
TALL FESCUE
r = −0·470
300
100
NUMBERS OF OTHER ROOTS
20
60
100
140
180
220
LEAF YIELD - MGMS.

FIGURE 20.

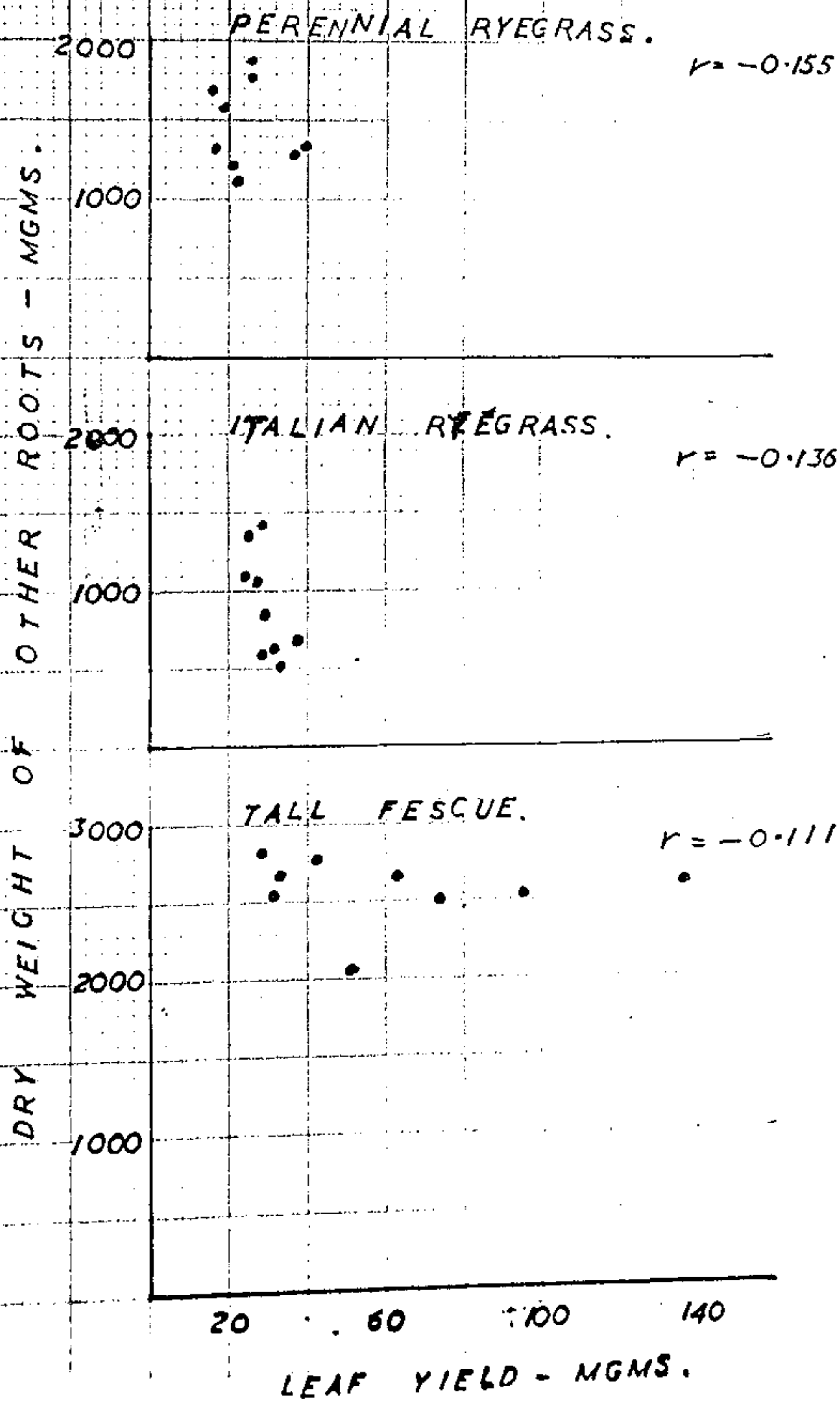

PERENNIAL RYEGRASS.
r = −0·155
ITALIAN RYEGRASS.
r = −0·136
TALL FESCUE.
r = −0·111
2000
1000
2000
1000
3000
2000
1000
20
60
100
140
DRY WEIGHT OF OTHER ROOTS - MGMS.
LEAF YIELD - MGMS.

TABLE 32. Correlation coefficients between numbers of roots other than white roots per plant, and the interpolated dry weights of leafage per plant per day for the same dates.

Species	Values of r Actual	Required at 5% level	Required at 1% level	Result of test
Perennial ryegrass	0.142	0.514	0.641	N.S.
Italian ryegrass	0.035	0.514	0.641	N.S.
Tall fescue	- 0.470	0.514	0.641	N.S.

TABLE 33. Correlation coefficients between dry weights of roots other than white roots per plant and the interpolated dry weights of leafage per plant per day for the same dates.

Species	Values of r Actual	Required at 5% level	Required at 1% level	Result of test
Perennial ryegrass	- 0.155	0.666	0.798	N.S.
Italian ryegrass	0.136	0.666	0.798	N.S.
Tall fescue	- 0.111	0.666	0.798	N.S.

The period covered by the calculations in Table 32 is from 4th December to 5th October inclusive, and in the case of Table 33, is from 20th April to 5th October inclusive. In no case, whether the correlation coefficients are calculated on root numbers or dry weights, is a significant correlation (positive or negative) attained, or even approached, between leaf yield and roots other than white roots. The only conclusion that can be drawn is that in these three species and under the conditions of this experiment, the numbers and dry weights of older roots per plant are independent of the leaf yield per plant.

SECTION V

DISCUSSION.

The discussion of the results obtained in this experiment will be presented in 5 sections as follows:-

(1) the experiment as a whole

(2) the root classes, and the staining patterns observed with tetrazolium salt.

(3) the numbers and dry weights of the root classes

(4) the relationship between top growth and root growth

(5) the relationships within the various measures of top growth.

(1) The experiment as a whole.

The results obtained in this experiment can only be strictly applied to the conditions which held during the experiment. These conditions differed considerably from normal pasture. The trial plants were spaced several inches apart, and this greatly reduced the effects from intraspecific competition, the only evidence of this competition showing in the perennial ryegrass tiller counts. There was no competition with other species, since the pipes at all times were maintained free of plants other than those in the experiment. This exclusion of clovers prevented the grass plants receiving the benefit of nitrogen fixed by the clovers' symbiotic root nodule bacteria, as obtained in any mixed grass-clover sward.

Possibly the major difference between the conditions in a normal pasture and in this experiment was the absence of the grazing animal. The technique of top cutting at fixed intervals with complete removal of herbage from the plots is a different proposition from the effects which a grazing animal imposes upon pasture plants. There were no additions of animal excrement to the plants as would have obtained under grazing, and apart from the massive fertilizer application during the establishment of the trial, there was no addition of any fertilizing agency. There was no stock trampling on the plants themselves, nor on the surrounding soil to cause consolidation; while the top cut was cleanly made with scissors through all tissue, so that the plants were not subjected to the tearing and pulling action of the grazing animal.

The seasonal root growth characters observed in this trial would probably be modified by grazing effects or by plant competition, although the major features shown experimentally here would be likely to remain. The elucidation of the degree to which these results would be modified under different conditions calls for further study.

The plan of the experiment proved to be satisfactory, from the viewpoints of ease of handling the material, and of examination of the results. It was realized that the use of nucleus stock seed in the ryegrass species, and of unselected seed samples in tall fescue and Poa annua, would introduce considerable genetic variation, although a conscious effort to reduce this was made by selecting uniform seedlings for planting out in the pipes. Both Yen (1947) and Edmond (1949) used clonal material, but although this overcame genetical diversity, they both introduced considerable variation into their experiments because of the difficulty of preparing tillers uniform in size and vigour.

The number of replications was sufficient to allow major differences between the species to be established as statistically significant. The fact that the standard errors calculated for the various characters considered, were mostly rather high, indicated that there was considerable variation in the plant material, but this was overcome in the statistical analyses by the large differences which were found between perennial ryegrass and tall fescue on the one hand, and Italian ryegrass on the other. This applied particularly in the case of white roots. Eight replications of each species at each lifting, is however likely to represent the minimum number which should have been employed. At certain liftings, one or more Italian ryegrass plants were dead, and this sometimes led to loss of statistical significance because of the increased residual effect in the analysis of variance. The successful use of only eight replications in this experiment bears out Edmond's (1949) contention that eight or ten replications should be sufficient to allow the establishment of at least major differences between species in root studies of this nature.

2. Root classes and staining patter : with tetrazolium salt.

The two root classes recognized in this experiment - white roots, and roots other than white roots - represent an over-simplification of the problem of root classification. In perennial ryegrass and crested dogstail, Jacques (1935) described three types of root.

(a) white roots, easily distinguished in the early stages by their greater diameter, glossiness, and straight, unbranched habit of growth, with abundant root hairs along the length of the root.

(b) truly fibrous roots, having at the outset a smaller diameter and a wavy growth habit.

(c) thin white roots, intermediate between the types above.

In the present experiment, white roots were easily distinguished and were used as an indication of new root initiation over the trial period. The remainder of the root system was treated as a complete unit, the total number and weight of these roots being used to give a picture of the size of the root system available for the support of the plant over the year. Nothing is known of the separate functions of the root types which make up the older part of the root system. The amount of work which would have been involved in this experiment in attempting to dissect out and measure root classes was far beyond the capacity of one person, but a detailed root classification could well be undertaken in the future.

In his discussion of white roots, Jacques (1935) pointed out that they possess a better conducting system than the fibrous roots, but are more liable to damage because they lack strengthening tissue. Their primary function is nutritional, and they are being actively formed during the winter following autumn sowing of the seed. The percentages determined in the present experiment for both the dry matter content, and the crude fibre content of these white roots, bear out the above observations. The low percentage values in both characters in relation to the older and more fibrous roots, indicate that the white roots are composed of young tissue, which presumably is at a high level of activity supplying the parent plant with both water and nutrients.

At a later stage, white roots lose their characteristics, and lateral branching develops. In Italian ryegrass at least, this change was deduced from the numbers of both white roots and roots other than white roots, to take place some 6 to 9 weeks after formation of the individual white root. This is only an assumption, and could not be measured because the experiment was not designed to allow any plant from being observed before it was lifted with its appropriate block. The only evidence of duration of "whiteness" in these roots is presented by Jacques (1935), who found that white roots commenced to branch out lateral roots after about the seventh week of growth. These two assessments are in general agreement.

The treatment of white roots as new roots in this experiment receives further indirect support from Edmond (1949) and Yen (1947). In the description of his weekly root pruning technique, Edmond writes of "removal of the light coloured new roots ....". Yen writes: "New roots were easily recognized from sloughed roots by their thickness, and from old unsloughed roots by their comparative softness and colour, which was white, and shiny in the early stages of development."

Loss of cortical tissue was first noticed in this present experiment early in March. This is nearly a month later than the first observations made of the same phenomenon by Yen (1947). He reported cortex sloughing over the proximal 3 to 4 inches of root by early February in Italian ryegrass, and towards the end of February in perennial ryegrass. Jacques (1941) has written: "The fact that there is deterioration in the cortex and the absorbing surface of the more superficial or older portions of roots before the dry weather sets in still further enhances the importance of the newer portion of root near the tip".

It would appear that the time when destructio... and loss of the cortex occurs in the part of the root near to the crown, will vary to some extent with the season. While the cortex on the older roots breaks down during the late summer, it would be expected that this process is accelerated under dry soil conditions. In the present experiment, reference to Table 2 and to the rainfall information in Appendix 3, shows that the 1952-53 season in the Manawatu while the experiment was in progress, was appreciably wetter than the average. More than 9 inches of rain fell during January 1953, and this would effectively prevent drought conditions in the soil for the following two or three months, even if rain had not fallen over that period. In addition, the plants in the present study were younger than those observed by either Jacques or Yen, and this factor, too, may have operated to delay the loss of cortex.

The fact that root stelar tissue stained throughout its entire length with tetrazolium salt, even after loss of cortex led to exposure of the stele, indicates continued activity in such roots. The feeding areas would be restricted to the distal portions of the root, and the lateral roots developed in this region. The stele would serve merely for conduction of water and solutes to the aerial portions of the plant, and the staining which occurred in the stele is sufficient evidence of this process. It can be concluded that although loss of cortex in the upper part of the older roots during summer and autumn impairs the uptake by the roots of nutrients and water from the superficial soil layers, these roots are still functional at lower soil depths. At times when the surface soil layers approach physiological dryness, so that secondary root hairs and any small roots feeding in this zone become inoperative, the deep activity of the older roots will be the major or sole source of water and solutes in the plant. In winter and early spring, the new white roots will be actively taking up nutrients in the re-wetted upper soil layers, to build the reserves in the plant that will be utilized by the spring flush of top growth.

The dense tetrazolium staining patterns that w : observed in all root tips, including those of lateral roots, indicates intense biological activity in these zones of cell differentiation and maturation. In timothy (Phleum pratense), Goodwin and Stepka (1945) distinguished four regions in the growing root tip over a distance of 1 millimetre; (a) the root cap, (b) the meristematic zone (0-300 mu), (c) a zone of active cell division and elongation (300-400 mu), and (d) a zone with no cell division and slow cell elongation (400-1000 mu). They further demonstrated that cell differentiation according to cell type occurred at different levels within the root; seive tubes matured within 230 mu of the root cap base, while the first xylary elements to show cell wall thickening were about 750 mu from the root cap. The intense staining observed in the present experiment was over a distance corresponding approximately to that occupied by the 4 zones in timothy. However, no zonations of the stain could be detected under the binocular microscope, so that Goodwin's and Stepka's observations in timothy could not be confirmed or disproved in the ryegrasses and tall fescue by this method of tetrazolium use. The sole conclusion here is that the root tip region in all roots was at a higher level of biological activity than was the remainder of the root system.

Attempts to cut sections of stained roots for the microscopic observation of specific tissues were unsuccessful, as there appeared to be some diffusion of the reduced formazan salt. The staining action of tetrazolium salts differs from that of normal vital stains which are absorbed by certain tissues, since the formazan salt is precipitated in minute crystals at the site of its reduction. Stafford (1951) suggested that selective adsorption by certain tissues may be involved in the apparent localization of reduced tetrazolium salts. Sonnenblick et al (1950) in sectioned onion roots found that formazan from the reduction of 2,3,5 triphenyl tetrazolium chloride began to diffuse out of the cells about 1 to 2 hours after the start of a test.

The conclusion which can be drawn from the current experiment, and from the findings of other workers, is that tetrazolium salt is a promising method for the determination of viability in roots, but that further study is necessary before it can be satisfactorily used with microscopic techniques. It is likely that some of the newer tetrazolium compounds may be useful for this purpose. Thus 2 - (p - iodophenyl) - 3 - (p - nitrophenyl) - 5 - phenyl - tetrazolium chloride is reported as being less photosensitive than the 2, 3, 5 - triphenyl-tetrazolium chloride or bromide, and gives a very rapid staining reaction with very little diffusion of the precipitate.

3. Root numbers and weights.

The results which have been presented for the various combinations of these characters - it will be necessary to include the number of tillers per plant in this discussion - show that Italian ryegrass possesses several features which effectively separate it from perennial ryegrass and tall fescue. This discussion aims primarily to show that the differences could be concerned in the longevity of the respective grass species.

In the analysis of these results, it was found that more consistent and more discerning conclusions could be drawn when root numbers were taken as the base instead of root weights. The weight of individual roots in the three species were not the same, tall fescue having values more than double those of the ryegrasses, with perennial ryegrass rather more (some 15%) than Italian ryegrass. Another reason for the relative lack of precision in the results based on weights is the wider variation which existed between plants of the same species in this character, and the smaller variation which existed between the numbers of roots.

The first feature of importance was the decrease in both tiller numbers per plant and roots other than white root numbers per plant in Italian ryegrass during February. Associated with this is the cortex tenderness first noticed in Italian ryegrass at the end of December, some 4 weeks earlier than in the other two species. From these results it can be concluded that the older Italian ryegrass roots are losing some of their effectiveness, or at least are being restricted in their feeding zones, at the end of the year; and this coincides with the decline in leaf production which was found after the cut on 22nd December. In the other species, where the cortex softness did not appear until late January, herbage yield was either maintained until the end of February (perennial ryegrass) or the peak of herbage growth was not reached until late in January (tall fescue).

The lowered leaf production in Italian ryegra after the end of December was partly associated with the decline in tiller and older root numbers. Although it is realized that the leaf-yield-per-tiller curves in figure 5 are based on insufficient data to be conclusive, there is no evidence that the rate of tiller growth in Italian ryegrass is much depressed below that of perennial ryegrass during the summer and autumn. The lowered production obtained in this trial is a reflection on the death of tillers, and the consequent loss of photosynthetic activity at this period.

The evidence therefore shows that the late summer and early autumn period may be critical for the survival of Italian ryegrass. Under competition effects in a pasture, such loss of tissue as was found in this experiment could lead to smothering of the weakened plants by the more vigorous species. This experiment did not elucidate the causes of the tiller and root losses in Italian ryegrass, and this should be the subject of further study.

The second feature of importance is that white root formation in Italian ryegrass was slower to reach appreciable levels than in perennial ryegrass or tall fescue. In all three species, white roots were first recorded on 9th March, but it was not until late April that the numbers per plant in Italian ryegrass became of the same order as in the other two species. This evidence accentuates the view already expressed that late summer and autumn is a critical period for Italian ryegrass. Not only is there a loss of photosynthetic and root tissues occurring in this species, but the formation of new roots does not reach appreciable levels until late autumn. Neither of these factors will favour longevity.

Soil moisture has been ignored in the present experiment, as a factor in new root initiation. Jacques and Edmond (1952) believe that the rate of root initiation is partly independent of soil moisture provided that the existing level is above the minimum needed for initiation. They found that root initiation almost ceased at the

10-12 per cent soil moisture level. In view of the wet season in which the current experiment was carried out, and the fact that conclusions on root initiation are concerned with the winter period when soil moisture is normally at high levels, it is unlikely that soil moisture had any influence on root initiation.

The third feature to be discussed is the greater numbers of white roots that were recorded in Italian ryegrass, compared with the other species. This was shown on a per tiller basis, where for the period from 20th April to 5th October inclusive, Italian ryegrass had a significantly greater number of white roots per tiller than either perennial ryegrass or tall fescue. The actual numbers of new white roots per tiller in Italian ryegrass from 1st June until 14th September inclusive, was of the order of 1.0, while in the other species for the same time it was approximately 0.4, or 2 white roots per 5 tillers.

This same feature was shown when the number of white roots per plant was expressed as a percentage of the total number of roots per plant. In Italian ryegrass, this value was greater than 30% from 1st June until 24th August, reaching a maximum value of over 40%. In both perennial ryegrass and tall fescue, the values approached but never reached 20%. Thus during the period after the middle of April until the middle of September, the root system of Italian ryegrass was composed to a large extent of new roots. It is possible that the greater nutritional activity of these new roots could underlie at least part of the higher leaf growth level found in Italian ryegrass during winter in comparison with perennial ryegrass.

This experiment was not designed to allow the examination of individual roots more than once - at the lifting of the appropriate block. Therefore no evidence was obtained about the length of time that new roots retained their "whiteness". An assessment was made in the case of Italian ryegrass of some 6 to 9 weeks, from the increase in number of roots other than white roots at the middle of

July after increases in white root numbers during ay and early June. This assessment agrees with that made by Jacques (1935), who found that white roots in perennial ryegrass commenced lateral branching some 7 weeks after formation, and hence lost their "white" characteristics.

If two assumptions are accepted as reasonable, then it becomes possible to prepare figures giving the hypothetical amount of root replacement which occurred in the root systems of each species. These assumptions are firstly, that the length of time a root retains its white characters is the same in all 3 species studied here, and secondly, that the length of time a root retains its white characters remains the same over the relevant period of the experiment (mid autumn to early spring). Table 34 sets out the relevant figures. The allowance of 40% calculated in column 3 is an empirical figure, adopted here to correct the total white root numbers for the fact that white root characters last longer than 6 weeks, and hence would have extended over two or more lifting dates.

TABLE 34. Hypothetical root replacement rate in 3 grass species

	Total number of white roots per plant recorded.	Adjusted number (40%) of white roots per plant	Average number of total roots per plant mid-November	% replacement of roots.
Perennial ryegrass	425.3	170	250	68
Italian ryegrass	623.6	250	250 *	100
Tall fescue	376.1	150	250	60

* This value of 250 in Italian ryegrass is rather high, as earlier evidence suggests that root numbers in this species in mid-November are below those in the other species. If this had been allowed for in computing the table, the effect would have been to reduce the percentage root replacement in perennial ryegrass and tall fescue.

While it is fully realized that the figures given in Table 34 are based on unproved assumptions, and that the resultant root replacement percentages can only be hypothetical, they ... support evidence discussed earlier dealing with the prominence of white roots in Italian ryegrass. The greater degree of root death and renewal which appears to be operating in this species could also be an agent in the relatively short life of this species. The effect would show in adverse seasons, when the environmental conditions depressing root initiation would also certainly be facilitating mortality in the older roots.

The evidence found that, from the beginning of June through until the latter half of September, there were consistently fewer roots other than white roots per Italian ryegrass tiller than per perennial ryegrass tiller, supports the view that the Italian ryegrass plant is more dependent upon new root formation for its mineral nutrition.

This section of the discussion has indicated four ways in which the root system of Italian ryegrass differs from those of the other experimental species, to the probable detriment of its longevity. In summary, they are: (a) a loss of root and photosynthetic tissue in late summer and autumn, plus early deterioration of the older roots, (b) fewer older roots per tiller during winter, (c) a relatively late start in the initiation of new white roots in late autumn and early winter, and (d) a larger proportion of the root system replaced during the winter, which will allow of vigorous root activity but which will also be susceptible to adverse soil conditions for root initiation.

4. Relationships between top growth and root growth.

The significant negative correlation which was found between both numbers and dry weights of white roots per plant, and the leaf yields per plant, in both the ryegrass species, can be interpreted as showing the differential seasonal growth between leaf tissues and the root system. During the winter, herbage growth is at low levels, while new root initiation, and the formation of an active root system, is proceeding vigorously. The emphasis in the plant at this period, is towards building-up a root system, and presumably food reserves in the storage tissues, that will be capable of supplying the great demands for nutrients made by the leaf growth flush in spring. This activity in winter can be modified by the environmental conditions; a common observation is that the spring leaf growth following the management method commonly known as "autumn-saved pasture" is both earlier and more vigorous than the spring leaf growth from a pasture which has been hard grazed in winter.

The relationship could not be shown to be statistically significant in tall fescue. The reason for this lay in the steady rate of root initiation in this species from March until late October, which could be represented very nearly by a straight line, while leaf growth followed a pronounced U-curve from late May until mid August, with the minimum values during July.

The relationship, which has been established statistically in the ryegrasses, confirms the observation in perennial ryegrass and cocksfoot by Edmond, and which is stated by Jacques and Edmond (1952) in these words: "The periods of maximum production of roots and tops did not coincide .... As root and shoot behaviour was comparable for all treatments, it would appear that the alternation between root and top growth was not in response to any stimulus developed in this experiment, but rather, was a response to stimuli affecting normal physiological development."

Similar relationships between top growth and root growth are recognized in American range grasses. This is clearly shown by McCarty and Price (1942), who found that carbohydrate storage by grasses is cyclic in nature. Minimum storage coincides with maximum top growth, while maximum storage occurs in the autumn at the completion of secondary herbage growth, in Bromus carinatus and Agropyron trachycaulum. Early spring growth is dependent on the presence of adequate carbohydrate reserves, and the amount of foliage present during the normal storage period determines the amount of carbohydrate reserve accumulated in roots and stem bases. These workers recommend that grazing should be slackened during the critical periods in the life cycles of range grasses; (a) during the active reproductive period from heading to seed ripeness, when plant reserves are at a minimum, and (b) during the early part of the normal storage period, when undue interference may leave insufficient time for complete regrowth and build-up of reserves.

5. Relationships in the top growth measurements.

The major features of the leaf dry matter yields, the dry matter percentages of the leaf tissues, and the number of tillers per plant have been presented in the first section of the results and need not be repeated here. There is one feature of the top growth, however, which does require further discussion.

Significant negative correlations were calculated in each species between leaf yields per plant and number of tillers per plant, despite the rather dissimilar curves for each species in both these factors. These negative correlations, which cover the period from early December until late in the following October, account for some 40 to 50 per cent of the variance. Much of the remaining variance will be due to the largely unexplained "peaks and troughs" in the values determined for each character, and which are evident in figures 2, 3 and 4. This is particularly the case in the number of tillers per plant in perennial ryegrass, where the large decreases which were found on 20th April, 22nd June and 14th September, were the main reason for the negative correlation in this species reaching significance at only the 5% level.

The trends in each component of this correlation behaved in the expected manner. Essentially, leaf yield per plant declined from the New Year, and followed the accepted growth patterns of low yield levels in winter, while the experiment ended just as the spring growth was commencing in the ryegrasses. The number of tillers per plant was increasing during the first few months of the experiment, as would be expected in young plants becoming established from August plantings. An exception to this is shown by Italian ryegrass, in which a decline in number of tillers per plant was recorded from the end of January until the end of March. In tall fescue, the increase in tiller numbers per plant was much more gradual than in perennial ryegrass, where the peak values were reached during

March. It is likely that most of the significance in the negative correlations, at least in perennial ryegrass and tall fescue, was derived from the behaviour of the two component characters over the earlier part of the experiment.

It would appear to be possible to explain the high tiller numbers per plant in both ryegrasses during the winter period when leaf yields were at low levels, and the decline which occurred in tiller numbers per plant in early spring as leaf yields increased, as an example of the phenomenon of apical dominance. Apical dominance, which has long been recognized by plant physiologists, although there is as yet no general agreement on the mode of the hormonal actions involved, is the limitation or complete inhibition of the development of lateral meristems by a vigorous terminal meristem. On removal of this terminal meristem, one or more of the lateral meristems close to the growth apex usually commence to grow more vigorously, and will in turn limit the growth of lateral meristems below them.

When leaf growth is active, there is a strong demand for metabolites by the existing main tillers, with a resultant starvation and suppression of potential lateral tillers. When leaf growth is at a low ebb, the demand for metabolites by the central tillers is not so strong, and a proportion becomes available to support lateral tillers which will now be initiated. In the present experiment, all tillers were bearing some green photosynthetic tissue, but many of them were very small, and contributing negligibly to leaf production. There is evidence from other sources that the shorter daylength associated with autumn and winter induces a tendency for shortening of leaf lengths. This has been reported by Peterson et al (1949) in _Poa pratensis_, and has been observed in perennial ryegrass by Mitchell (personal communication). This factor may have been operative in the small size of the winter tillers.

A study of young vegetative ryegrass plants, reported by Mitchell

(1953), demonstrated that such treatments as shading, reduction of the period of illumination, exposure to high temperatures, and partial defoliation, reduced lateral tiller formation. Since such treatments also control either the potential rate of formation or rate of utilization of energy substrate for growth or respiration, Mitchell concluded that in Lolium, the development of the lateral tillers can be regulated by the general level of energy substrate in the plant. The winter period has lower temperatures, shorter daylengths, and lower light intensities than summer. Under the spaced plant conditions which applied in the current experiment, the fall in light intensity due to the time of year is unlikely to reduce appreciably the rate of photosynthesis, while the lower winter temperatures will more than offset the shorter daylengths in their effects upon the energy substrate levels in the plant (Mitchell, personal communication). During the winter, therefore, lateral tiller formation can proceed apace, although the size of the individual tillers will be restricted by such factors as the general low levels of growth activity at that season, and the influence of daylength upon leaf length.

At the end of December, the leaf yields per tiller (figure 5) show considerable differences between the species, and tiller numbers per plant also show differences at this time. Tall fescue has the highest leaf yield per tiller of approximately 4 milligrams of dry tissue per day, and each plant averages some 50 tillers. In Italian ryegrass, the leaf yield per tiller is about 2.5 milligrams per day, with approximately 60 tillers, while perennial ryegrass is producing nearly 1.5 of dry leaf tissue per day, with some 80 tillers per plant. It would thus appear that leaf yield at this period is a reflection of tiller size, since there is an inverse relationship between these two characters. A similar position also applied during winter, when a higher leaf yield per plant in Italian ryegrass, in comparison with perennial ryegrass, was due to a higher leaf yield per tiller (figure 5), and hence larger tillers, while the number of tillers per plant was less. This relationship is further evidence supporting the explanation advanced here for the negative correlations between leaf yield and tiller numbers per plant.

SECTION VI.

SUMMARY OF CONCLUSIONS

This section sets out a brief summary of the conclusions which have been drawn from the results, and discussed, in the preceding sections.

1. The planning and layout of the experiment was efficient, since the results allowed satisfactory statistical analyses to be calculated, and interpretations to be drawn.

2. There is breakdown of the root cortical tissues in the middle of summer, the actual timing varying with different species, and probably with seasonal conditions. The stelar tissue remains intact even after complete exposure in the upper part of the root, and functions as conducting tissue between the distal feeding parts of the roots, and the aerial part of the plant.

3. New roots are initiated from early autumn at an increasing rate up until late in winter. The rate of initiation then declines. Plants are building-up a vigorous root system capable of supplying water and solutes at the high levels required by the spring flush of leaf growth.

4. The use of 2, 3, 5 - triphenyl - tetrazolium bromide as an indicator of viable tissue was successful. Further study is required before its full potentialities are realized, and a microscopic technique worked out.

5. Italian ryegrass differed from perennial ryegrass and tall fescue in four characters. Since each of these characters could operate against the survival of Italian ryegrass plants, they may be concerned in the relatively short life of this species in comparison

with perennial ryegrass.

(a) There was earlier loss of root cortex in Italian ryegrass and there was death of both tillers and roots after the peak leaf growth had been reached, and as leaf growth fell sharply away.

(b) There were fewer older roots per tiller in Italian ryegrass than in the other species, during the winter period.

(c) There was delayed initiation of new roots at an appreciable level for some 4 to 6 weeks later than in perennial ryegrass.

(d) There was a greater proportion of the root system replaced by new roots during the winter in Italian ryegrass.

6. There were significantly negative correlations between leaf yield, and new root numbers, per plant during the autumn winter and early spring in both ryegrasses. This is the normal physiological growth cycle in these species.

7. There were significantly negative correlations between leaf yield and tiller numbers, per plant, during the experimental period. An explanation is advanced on the basis of apical dominance by vigorously growing central tillers.

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APPENDIX 1.

Results of Top Cutting Treatment

Perennial Ryegrass

Date of cutting	Sample "A" No. of plants	Sample "A" Green-weight, gms.	Sample "A" Dry matter %	Sample "B" No. of plants	Sample "B" Green-weight, gms.	Sample "B" Dry matter %	All Plants No. of plants	All Plants Green-weight, gms.	All Plants Dry matter %	All Plants Dry-weight gms.	All Plants Dry weight per plant per day, mgms.
17th Sept. 1952	64	35.8	28.9	72	40.8	26.8	136	76.6	27.8	21.32	-
1st October	64	107.6	20.0	72	131.6	19.8	136	239.2	19.9	47.60	25
15th October	64	234.8	19.1	72	279.7	18.1	136	504.5	18.6	93.84	49
30th October	64	362.7	19.9	72	434.1	19.8	136	796.8	19.8	157.76	77
13th November	64	381.2	21.2	72	423.3	21.5	136	804.5	21.3	171.36	90
28th November	64	321.1	20.7	72	371.9	21.4	136	693.0	21.0	145.52	71
11th December	64	366.3	20.3	64	375.1	20.2	128	741.4	20.2	149.76	90
22nd December	64	341.9	20.4	64	329.5	20.5	128	671.4	20.4	136.96	97
6th Jan. 1953	64	408.6	22.2	56	376.7	21.1	120	785.3	21.7	170.40	95
21st January	64	378.0	22.9	56	354.7	22.2	120	732.7	22.6	165.60	92
4th February	56	311.1	21.2	56	301.7	21.2	112	612.8	21.2	129.92	83
18th February	48	269.6	21.4	56	299.5	21.1	104	569.1	21.2	120.64	83
4th March	48	263.5	21.2	56	296.5	20.4	104	560.0	20.8	116.48	80
18th March	40	125.7	24.0	56	167.2	23.2	96	292.9	23.6	69.12	51
2nd April	40	116.4	24.3	48	147.2	23.2	88	263.6	23.7	62.48	47
16th April	40	88.2	23.7	48	111.1	23.2	88	199.3	23.4	46.64	58
4th May	40	133.1	23.5	40	125.5	23.0	80	258.6	23.2	60.00	42
20th May	32	67.6	23.4	40	86.9	23.3	72	154.5	23.3	36.00	31
8th June	24	45.9	23.0	40	74.8	22.7	64	120.7	22.8	27.52	23
2nd July	24	46.2	25.2	32	69.3	25.8	56	115.5	25.6	28.56	21
23rd July	24	36.0	22.8	24	38.5	23.7	48	74.5	23.2	17.28	17
14th August	-	-	-	-	-	-	40	59.2	25.0	14.80	17
8th September	-	-	-	-	-	-	32	54.9	23.9	13.12	16
23rd September	-	-	-	-	-	-	24	47.5	20.7	9.84	27
19th October	-	-	-	-	-	-	16	51.2	19.7	10.08	24

APPENDIX 1. (Continued) Results of Top Cutting Treatment.

Italian Ryegrass

Date of cutting	Sample A			Sample B			All Plants				
	No. of plants	Green-weight, gms.	Dry matter %	No. of plants	Green-Weight, gms.	Dry matter %	No. of plants	Green-Weight, gms.	Dry matter %	Dry weight gms.	Dry wight per plant per day mgms.
17th Sept. 1952	63	71.3	18.7	72	83.7	20.3	135	155.0	19.7	30.54	-
1st October	63	229.8	17.3	70	267.0	17.4	133	496.8	17.4	86.45	46
15th October	63	376.0	16.3	69	394.0	17.2	132	770.0	16.8	129.36	70
30th October	60	360.1	17.7	67	404.7	18.5	127	764.8	18.1	138.43	73
13th November	60	398.4	18.6	67	468.4	19.1	127	866.8	18.9	163.83	92
28th November	59	318.4	17.7	66	363.4	17.5	125	681.8	17.6	120.00	64
11th December	59	383.6	17.4	58	373.9	17.2	117	757.5	17.3	131.04	86
22nd December	59	340.7	17.0	58	344.0	18.2	117	684.7	17.6	120.51	94
6th January, 1953	59	321.3	17.8	50	277.0	19.1	109	598.3	18.4	110.09	67
21st January	59	288.8	20.4	50	240.2	20.4	109	529.0	20.4	107.91	66
4th February	51	190.5	17.0	49	186.6	17.9	100	377.1	17.5	66.00	47
18th February	47	228.2	16.5	49	235.2	18.3	96	463.4	17.4	80.64	60
4th March	45	170.2	16.6	49	188.4	18.2	94	358.6	17.3	62.04	47
18th March	37	105.0	18.8	48	138.5	19.7	85	243.5	19.2	46.75	39
2nd April	36	103.7	19.4	41	129.6	20.2	77	233.3	19.8	46.20	40
16th April	36	81.6	19.5	41	92.1	19.4	77	173.7	19.5	33.88	31
4th May	36	131.4	19.5	33	129.1	19.8	69	260.5	19.6	51.06	41
20th May	28	80.9	19.6	33	96.1	19.1	61	177.0	19.3	34.16	35
8th June	20	58.5	18.9	33	97.7	19.0	53	156.2	19.0	29.68	29
2nd July	20	68.2	20.8	25	84.7	20.9	45	152.9	20.9	31.95	30
23rd July	20	55.0	18.7	20	50.2	20.2	40	105.2	19.4	20.40	24
14th August	-	-	-	-	-	-	35	87.5	20.0	17.50	23
8th September	-	-	-	-	-	-	28	96.7	19.4	18.76	27
23rd September	-	-	-	-	-	-	22	62.3	17.2	10.78	33
19th October	-	-	-	-	-	-	15	50.6	16.9	8.55	22

APPENDIX 1. (Continued)

Results of Top Cutting Treatment

Tall fescue

Date of cutting	Sample A			Sample B			All Plants				
	No. of plants	Green-weight, gms.	Dry matter %	No. of plants	Green-weight gms.	Dry matter %	No. of plants	Green-weight gms.	Dry matter %	Dry weight gms.	Dry weight per plant per day mgms.
17th Sept. 1952	64	18.3	19.1	72	21.0	19.7	136	39.3	19.3	7.59	-
1st October	64	69.5	18.8	72	77.1	17.9	136	148.6	18.3	27.20	14
15th October	64	96.6	16.5	72	105.8	17.0	136	202.4	16.8	34.00	18
30th October	64	274.2	17.4	72	334.6	17.0	136	608.8	17.2	104.72	51
13th November	64	381.0	18.2	72	421.6	18.5	136	802.6	18.3	146.88	77
28th November	64	455.3	18.6	72	539.1	18.6	136	994.4	18.6	184.96	91
11th December	64	658.2	17.2	64	657.4	19.0	128	1315.6	18.0	236.80	142
22nd December	64	600.9	17.9	64	623.7	19.2	128	1224.6	18.5	226.56	161
6th Jan., 1953	64	882.8	18.9	56	781.1	20.0	120	1663.9	19.4	322.80	179
21st January	64	941.5	20.9	56	858.5	20.7	120	1800.0	20.8	374.40	208
4th February	56	714.0	18.3	56	738.3	18.1	112	1452.3	18.2	264.32	169
18th February	48	650.6	18.2	56	780.1	17.9	104	1430.7	18.1	258.96	178
4th March	48	565.6	17.9	56	675.3	17.4	104	1240.9	17.6	218.40	150
18th March	40	315.7	19.6	56	453.3	19.7	96	769.0	19.6	150.72	112
2nd April	40	353.3	19.6	48	436.9	19.7	88	790.2	19.6	154.88	117
16th April	40	204.9	20.1	48	239.4	20.6	88	444.3	20.4	90.64	74
4th May	40	254.2	21.2	40	245.8	22.0	80	500.0	21.6	108.00	75
20th May	32	118.6	20.6	40	148.3	20.4	72	266.9	20.5	54.72	48
8th June	24	79.1	22.1	40	133.3	22.5	64	212.4	22.3	47.36	39
2nd July	24	61.4	25.2	32	77.6	24.6	56	149.0	24.8	36.96	28
23rd July	24	56.6	25.2	24	60.9	23.0	48	117.5	24.1	28.32	28
14th August	-	-	-	-	-	-	40	124.9	23.7	29.60	34
8th September	-	-	-	-	-	-	32	288.9	20.6	59.52	74
23rd September	-	-	-	-	-	-	24	247.7	18.6	46.08	128
19th October	-	-	-	-	-	-	16	354.9	17.4	61.76	148

APPENDIX 2.

(All weights are expressed in milligrams)

Individual plant root results: 1st lifting: 4/12/52.

Species	Perennial ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	88	75	87	82	36	87	73	96
No. roots other than white	157	184	167	240	148	207	147	215
Fresh wt. roots other than white	2335	2747	2677	2432	1792	3165	3632	2906
No. roots other than white per tiller	1.79	2.45	1.92	2.93	4.11	2.38	2.01	2.24

Species	Italian ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	45	14	18	34	20	35	13	21
No. roots other than white	104	63	85	56	55	123	64	65
Fresh wt. roots other than white	2513	657	908	2481	2653	1601	499	906
No. roots other than white per tiller	2.31	4.50	4.72	1.65	2.75	3.52	4.91	3.10

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	62	42	37	55	56	49	41	60
No. roots other than white	167	180	103	135	146	143	142	154
Fresh wt. roots other than white	3135	2341	2390	3204	2857	3021	3307	3101
No. roots other than white per tiller	2.69	4.29	2.79	2.45	2.61	2.92	3.46	2.57

APPENDIX 2 (Continued)

Individual plant roots results: 2nd lifting: 29/12/52

Species	Perennial ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	66	53	58	76	77	39	91	73
No. roots other than white	320	288	370	384	353	169	374	395
Fresh wt. roots other than white	2412	1609	2298	3140	3466	2150	4587	2561
No. roots other than white per tiller	4.85	5.44	6.38	5.06	4.58	4.34	4.11	5.41

Species	Italian ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	57	21	41	42	55	27	32	47
No. roots other than white	294	102	232	245	272	144	171	219
Fresh wt. roots other than white	3471	857	1281	2332	2801	809	1237	2825
No. roots other than white per tiller	5.16	4.86	5.66	5.84	4.95	5.33	5.34	4.66

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	45	37	49	41	65	32	54	48
No. roots other than white	194	184	188	165	196	119	179	159
Fresh wt. roots other than white	3379	2518	2970	3817	5070	2546	3722	2636
No. roots other than white per tiller	4.31	4.98	3.84	4.02	3.02	3.72	3.32	3.32

APPENDIX 2. (Continued)

Individual plant root results: 3rd lifting: 26/1/53.

Species	Perennial Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	118	82	86	67	67	62	93	97
No. roots other than white	355	250	273	202	198	217	246	294
Fresh wt. roots other than white	3412	1656	2869	2099	2418	1473	2585	2976
No. roots other than white per tiller	3.01	3.05	3.17	3.02	2.96	3.50	2.65	3.03

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	113	46	44	25	72	75	48	54
No. roots other than white	289	128	122	82	220	238	149	137
Fresh wt. roots other than white	1636	996	758	695	1976	1376	1220	993
No. roots other than white per tiller	2.56	2.78	2.77	3.28	3.06	3.18	3.10	2.86

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	50	34	25	54	36	46	48	52
No. roots other than white.	224	184	136	233	204	233	221	260
Fresh Wt. roots other than white	3149	2627	2910	4086	3380	3965	4344	3073
No. roots other than white per tiller	4.48	5.41	5.44	4.32	5.66	5.07	4.61	5.00

APPENDIX 2. (Continued)

Individual plant root results: 4th lifting: 16/2/53.

Species	Perennial Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	95	83	64	161	119	52	184	88
No. roots other than white	329	243	201	436	390	203	622	332
Fresh wt. roots other than white	3519	2268	1147	3980	2226	922	4240	1704
No. roots other than white per tiller	3.46	2.93	3.14	2.71	3.28	3.91	3.38	3.77

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	Dead	Dead	12	Dead	45	72	22	Dead
No. roots other than white	-	-	77	-	192	284	147	-
Fresh wt. roots other than white	-	-	201	-	1687	1361	606	-
No. roots other than white per tiller	-	-	6.42	-	4.26	3.95	6.69	-

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	65	46	65	82	50	46	50	31
No. roots other than white	255	178	263	275	221	191	219	192
Fresh wt. roots other than white	3995	1569	3681	6114	3763	1848	3765	3580
No. roots other than white per tiller	3.92	3.87	4.05	3.35	4.42	4.15	4.38	6.20

APPENDIX 2. (Continued)

Individual plant root results: 5th lifting: 9/3/53.

Species	Perennial Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	99	162	202	59	114	188	209	118
No. roots other than white	346	410	513	197	354	436	458	358
No. white roots	23	19	37	11	15	19	46	4
No. roots other than white per tiller	3.50	2.53	2.54	3.34	3.11	2.31	2.19	3.04
No. white roots per tiller	0.23	0.12	0.18	0.19	0.13	0.11	0.22	0.03
No. white roots as % No. total roots	6.2	4.4	6.7	5.3	4.1	4.2	9.1	1.1

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	97	60	13	43	41	32	30	7
No. roots other than white	263	153	105	109	115	139	114	42
No. white roots	11	4	2	-	7	13	14	2
No. roots other than white per tiller	2.71	2.55	8.09	2.54	2.81	4.35	3.79	6.00
No. white roots per tiller	0.11	0.07	0.15	-	0.17	0.41	0.47	0.29
No. white roots as % No. total roots	4.0	2.5	1.9	-	5.7	8.6	10.9	4.5

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	54	43	53	32	73	46	52	67
No. roots other than white	256	194	234	182	201	223	191	210
No. white roots	31	15	29	8	18	41	6	21
No. roots other than white per tiller	4.74	4.51	4.41	5.69	2.75	4.85	3.67	3.14
No. white roots per tiller	0.57	0.35	0.55	0.25	0.25	0.89	0.12	0.31
No. white roots as % No. total roots	10.8	7.2	11.0	4.2	8.2	15.5	3.0	9.1

APPENDIX 2. (Continued)

Individual plant root results: 6th lifting: 30/3/53.

Species	Perennial Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	82	190	140	166	137	196	209	62
No. roots other than white.	237	476	291	300	299	453	387	153
No. white roots	8	8	15	22	7	20	17	12
No. roots other than white per tiller	2.89	2.51	2.08	1.81	2.18	2.31	1.85	2.47
No. white roots per tiller	0.10	0.04	0.11	0.13	0.05	0.10	0.08	0.19
No. white roots as % no. total roots	3.3	1.7	4.9	6.8	2.3	4.2	4.2	7.3

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	Dead	28	20	3	16	82	35	13
No. roots other than white	-	61	71	-	53	249	166	71
No. white roots	-	17	14	7	13	7	27	-
No. roots other than white per tiller	-	2.18	3.55	-	3.31	3.03	4.74	5.45
No. white roots per tiller	-	0.61	0.70	2.33	0.81	0.09	0.77	-
No. white roots as % No. total roots	-	21.8	16.5	100.0	19.7	2.7	14.0	-

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	63	49	59	71	66	83	45	76
No. roots other than white	278	191	154	232	207	248	227	268
No. white roots	33	60	12	34	16	25	18	32
No. roots other than white per tiller	4.42	3.90	2.62	3.27	3.14	2.99	5.05	3.53
No. white roots per tiller	0.52	1.22	0.20	0.48	0.24	0.30	0.40	0.42
No. white roots as % No. total roots	10.6	23.9	7.2	12.8	7.2	9.2	7.3	10.7

Individual plant root results: 7th lifting; 20/4/53.

Species	Perennial Ryegrass							
Plant No	1	2	3	4	5	6	7	8
No. tillers	114	123	56	86	155	162	53	63
No. roots other than white	441	341	227	307	480	463	222	227
Fresh wt. roots other than white	6498	5993	2289	3753	7394	9519	2101	3191
Dry wt. roots other than white	1530	1521	608	1001	1941	2536	596	923
No. white roots	27	34	10	10	61	31	9	11
Fresh wt. white roots	436	522	151	101	904	347	108	104
Dry wt. white roots	56	73	34	13	133	60	17	16
No. roots other than white per tiller	3.86	2.77	4.06	3.56	3.09	2.86	4.19	3.61
Dry. wt. roots other than white per tiller	13.4	12.4	10.9	11.6	12.5	15.6	11.3	14.6
No. white roots per tiller	0.24	0.28	0.18	0.12	0.40	0.19	0.17	0.17
Dry wt. white roots per tiller	0.5	0.6	0.6	0.2	0.9	0.4	0.3	0.3
No. white roots as % No. total roots	5.8	9.1	4.2	3.2	11.3	6.3	3.9	4.6
Dry wt. white roots as % dry wt. total roots.	3.5	4.6	5.3	1.3	6.4	2.3	2.8	1.7
D.M. % roots other than white	23.6	25.4	26.6	26.7	26.3	26.6	28.4	28.9
D.M. % white roots	12.8	14.0	22.5	12.9	14.7	17.3	15.7	15.4

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	18	48	9	57	53	28	37	36
No. roots other than white	102	166	73	203	252	28	89	81
Fresh wt. roots other than white	666	2690	272	3200	4587	654	944	1869
Dry wt. roots other than white	192	745	92	859	1255	199	313	573
No. white roots	8	39	17	56	39	16	21	12
Fresh wt. white roots	56	480	255	777	608	230	224	177
Dry wt. white roots	8	72	45	124	88	31	31	24
No. roots other than white per tiller	5.67	3.46	8.11	3.57	4.76	1.00	2.41	2.25
Dry wt. roots other than white per tiller	10.7	15.5	10.2	15.1	23.7	7.1	8.5	15.9
No. white roots per tiller	0.44	0.81	1.89	0.98	0.74	0.57	0.57	0.33
Dry wt. white roots per tiller	0.4	1.5	5.0	2.2	1.7	1.1	0.8	0.7
No. white roots as % No. total roots	7.3	19.0	18.9	21.1	13.4	36.4	19.1	12.9
Dry wt. white roots as % dry wt. total roots	4.0	8.8	32.8	12.6	6.6	13.5	9.0	4.0
D.M. % roots other than white	28.8	27.7	33.8	26.8	27.4	30.4	33.2	30.7
D.M. % white roots	14.3	15.0	17.8	16.0	14.5	13.5	13.8	13.6

APPENDIX 2. (Continued)

Individual plant root results: 7th lifting: 20/4/53.

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	79	47	42	55	80	86	35	48
No. roots other than white	278	245	196	263	320	357	237	222
Fresh wt. roots other than white	10498	12877	6517	9856	13088	13397	5727	7415
Dry wt. roots other than white	2783	3102	1753	2428	3222	3143	1609	2127
No. white roots	53	23	25	5	31	34	25	21
Fresh wt. white roots	2108	1106	900	102	718	1107	567	728
Dry wt. white roots	440	267	138	18	108	181	106	98
No. roots other than white per tiller	3.52	5.21	4.66	4.78	4.00	4.15	6.78	4.63
Dry. wt. roots other than white per tiller	35.2	66.1	41.7	44.2	40.2	36.6	46.0	44.0
No. white roots per tiller	0.67	0.49	0.60	0.09	0.39	0.40	0.71	0.44
Dry wt. white roots per tiller	5.6	5.7	3.3	0.3	1.4	2.1	3.0	2.0
No. white roots as % No. total roots.	16.0	8.6	11.3	1.9	8.8	8.7	9.6	8.6
Dry wt. white roots as % dry wt. total roots	13.6	7.9	7.3	0.7	3.2	5.4	6.2	4.4
D.M. % roots other than white	26.5	24.1	26.9	24.6	24.6	23.5	28.1	28.7
D.M. % white roots	20.9	24.1	15.3	17.7	15.0	16.4	18.7	13.5

APPENDIX 2. (Continued)

Individual plant root results: 8th lifting: 11/5/53.

Species	Perennial ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	58	108	117	134	140	161	321	131
No. roots other than white	127	258	274	279	302	285	523	246
Fresh wt. roots other than white	2101	4051	5959	4463	5950	3730	7424	2916
Dry wt. roots other than white	617	1063	1550	1430	1724	1078	2015	844
No. white roots	15	27	45	32	50	69	109	38
Fresh wt. white roots	202	343	502	283	1036	899	1816	762
Dry wt. white roots	30	49	81	48	159	118	286	149
No. roots other than white per tiller	2.19	2.39	2.35	2.08	2.16	1.77	1.63	1.88
Dry wt. roots other than white per tiller	10.7	9.9	13.2	10.6	12.4	6.7	6.3	6.5
No. white roots per tiller	0.26	0.25	0.38	0.24	0.36	0.43	0.34	0.29
Dry wt. white roots per tiller	0.5	0.5	0.7	0.4	1.1	0.7	0.9	1.1
No. white roots as % No. total roots	10.6	9.5	14.1	10.3	14.2	19.5	17.2	13.4
Dry wt. white roots as % dry wt. total roots	4.6	4.4	5.0	3.3	8.4	9.9	12.4	15.0
D.M. % roots other than white	29.4	26.2	26.0	32.0	29.0	28.9	27.1	28.9
D.M. % white roots	14.9	14.3	16.1	17.0	15.4	13.1	15.8	19.6

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	56	46	78	38	92	42	62	29
No. roots other than white	252	124	124	86	267	99	76	95
Fresh wt. roots other than white	4598	1898	3177	1010	4201	1942	2086	1067
Dry wt. roots other than white	1217	510	818	320	1146	533	615	290
No. white roots	24	29	69	31	45	42	29	13
Fresh wt. white roots	460	430	1833	529	484	621	710	90
Dry wt. white roots	78	67	280	82	74	110	80	15
No. roots other than white per tiller	4.50	2.70	1.59	2.26	2.90	2.36	1.22	3.27
Dry wt. roots other than white per tiller	21.8	11.1	10.5	8.4	12.5	12.7	9.9	10.0
No. white roots per tiller	0.43	0.62	0.89	0.82	0.49	1.00	0.47	0.45
Dry wt. white roots per tiller	1.4	1.5	3.6	2.2	0.8	2.6	1.3	0.5
No. white roots as % No. total roots	8.7	19.0	35.8	26.5	14.4	29.8	27.6	12.0
Dry wt. white roots as % dry wt. total roots	6.0	11.6	25.5	20.4	6.1	17.1	11.5	4.9
D.M. % roots other than white	26.5	26.9	25.8	31.7	27.3	27.5	29.5	27.2
D.M. % white roots	17.0	15.6	15.3	15.5	15.3	17.7	11.3	16.7

APPENDIX 2, (Continued)

Individual plant root results: 8th lifting: 11/5/53.

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	63	59	64	72	85	93	39	63
No. roots other than white	225	229	222	241	252	251	211	268
Fresh wt. roots other than white	13121	7998	6746	9536	9264	12374	6780	15207
Dry wt. roots other than white	3197	2179	1728	2727	2443	3262	1781	4057
No. white roots	38	-	19	51	27	50	9	18
Fresh wt. white roots	1815	-	934	2360	1428	2934	240	725
Dry wt. white roots	284	-	161	407	266	385	32	125
No. roots other than white per tiller	3.57	3.88	3.47	3.35	2.96	2.70	5.42	4.25
Dry wt. roots other than white per tiller	50.8	37.0	27.0	37.8	28.8	35.1	45.7	64.4
No. white roots per tiller	0.60	-	0.30	0.71	0.32	0.54	0.23	0.29
Dry wt. white roots per tiller	4.5	-	2.5	5.7	3.1	4.1	0.8	2.0
No. white roots as % No. total roots	14.5	-	7.9	17.5	9.7	16.6	4.1	6.3
Dry wt. white roots as % dry wt. total roots	8.2	-	8.5	13.0	9.8	10.5	1.8	3.0
D.M. % roots other than white	24.4	27.2	25.6	28.6	26.4	26.4	26.3	26.7
D.M. % White roots	15.7	-	17.2	17.3	18.6	13.1	13.3	17.2

APPENDIX 2. (Continued)

Individual plant root results: 9th lifting 1/6/53.

Species	Perennial Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	126	66	70	185	211	98	87	154
No. roots other than white	375	200	232	390	386	206	279	259
Fresh wt. roots other than white	8442	2456	3362	8880	7894	4230	3584	8084
Dry wt. roots other than white	2099	632	915	2419	2010	1119	1023	2002
No. white roots	51	37	42	41	50	34	40	43
Fresh wt. white roots	810	735	813	722	1288	676	655	780
Dry wt. white roots	139	116	115	89	184	104	113	104
No. roots other than white per tiller	2.98	3.04	3.32	2.11	1.83	2.10	3.21	1.68
Dry wt. roots other than white per tiller	16.7	9.5	13.1	13.1	9.5	11.4	11.8	13.0
No. white roots per tiller.	0.40	0.56	0.60	0.22	0.24	0.35	0.46	0.28
Dry wt. white roots per tiller	1.1	1.8	1.6	0.5	0.9	1.1	1.3	0.7
No. white roots as % No. total roots	12.0	15.6	15.3	9.5	11.5	14.2	12.5	14.2
Dry wt. white roots as % dry wt. total roots	6.2	15.5	11.2	3.5	8.4	8.5	10.0	4.9
D.M. % roots other than white	24.9	25.7	27.2	27.2	25.5	26.5	28.5	24.8
D.M. % white roots	17.2	15.8	14.2	12.3	14.3	15.4	17.3	13.3

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	47	dead	56	8	48	82	57	89
No. roots other than white	114	-	83	31	106	136	87	102
Fresh wt. roots other than white	2268	-	2680	135	2033	3123	3817	2214
Dry wt. roots other than white	654	-	682	48	592	820	1049	588
No. white roots	42	-	36	-	53	82	87	59
Fresh wt. white roots	843	-	505	-	753	2679	1931	1142
Dry wt. white roots	118	-	84	-	120	407	280	148
No. roots other than white per tiller	2.43	-	1.49	3.88	2.21	1.66	1.53	1.15
Dry wt. roots other than white per tiller	13.9	-	12.2	6.0	12.4	10.0	18.4	6.6
No. white roots per tiller	0.89	-	0.64	-	1.10	1.00	1.53	0.66
Dry wt. white roots per tiller	2.5	-	1.5	-	2.5	5.0	4.9	1.7
No. white roots as % No. total roots	26.9	-	30.2	-	33.4	37.6	50.0	36.6
Dry wt/ white roots as % dry wt. total roots.	15.3	-	11.0	-	16.8	33.2	21.1	20.1
D.M. % roots other than white	28.8	-	25.5	35.6	29.1	26.3	27.5	26.6
D.M. % white roots	14.0	-	16.6	-	15.9	15.2	14.5	13.0

APPENDIX 2. (Continued)

Individual plant root results: 9th lifting: 1/6/53.

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	42	57	84	85	83	86	56	85
No. roots other than white	231	232	256	328	240	307	202	317
Fresh wt. roots other than white	9443	5873	11311	14357	8820	8176	8839	11714
Dry wt. roots other than white	2807	1753	3298	4084	2402	2095	2657	3221
No. white roots	18	24	43	34	42	30	25	51
Fresh wt. white roots	838	654	1422	1145	2413	907	1193	2010
Dry wt. white roots	189	132	315	227	451	154	216	378
No. roots other than white per tiller	5.50	4.07	3.05	3.86	2.89	3.57	3.61	3.73
Dry wt. roots other than white per tiller	66.9	30.8	39.2	48.1	29.0	24.4	47.4	38.0
No. white roots per tiller	0.43	0.42	0.51	0.40	0.51	0.35	0.45	0.60
Dry wt. white roots per tiller	4.5	2.3	3.8	2.7	5.4	1.8	3.9	4.4
No. white roots as % No. total roots	7.2	9.4	14.4	9.4	14.9	8.9	11.0	13.9
Dry wt. white roots as % dry wt. total roots	6.3	7.0	8.7	5.3	15.8	6.9	7.5	10.5
D.M. % roots other than white	29.7	29.9	29.2	28.5	27.2	25.6	30.1	27.5
D.M. % white roots	22.6	20.2	22.2	19.8	18.7	17.0	18.1	18.8

APPENDIX 2. (Continued)

Individual plant root results: 10th lifting: 22/6/53.

Species	Perennial Ryegrass							
Plant No	1	2	3	4	5	6	7	8
No. tillers	147	111	48	115	78	169	126	75
No. roots other than white	241	157	85	422	185	283	273	130
Fresh wt. roots other than white	5929	2057	866	5399	2977	5144	6544	2096
Dry wt. roots other than white	1724	641	240	1682	901	1409	1800	625
No. white roots	30	20	27	48	28	82	81	28
Fresh wt. white roots	568	334	405	1088	352	1944	1965	635
Dry wt. white roots	85	37	77	223	48	307	310	112
No. roots other than white per tiller	1.65	1.42	1.78	3.66	2.37	1.67	2.17	1.73
Dry. wt. roots other than white per tiller	11.7	5.8	5.0	14.7	11.6	8.3	14.3	8.3
No. white roots per tiller	0.20	0.18	0.56	0.42	0.36	0.49	0.64	0.37
Dry wt. white roots per tiller	0.6	0.3	1.6	1.9	0.6	1.8	2.5	1.5
No. white roots as % no. total roots	11.1	11.3	24.1	10.2	13.2	22.5	22.9	17.7
Dry wt. white roots as % dry wt. total roots.	4.7	5.5	24.3	11.7	5.1	17.9	14.7	15.2
D.M. % roots other than white	29.1	31.2	27.7	31.2	30.3	27.4	27.5	29.8
D.M. % white roots	15.0	11.1	19.0	20.5	13.6	15.8	15.8	17.6

Species	Italian Ryegrass.							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	24	39	131	112	56	48	39	97
No. roots other than white	42	77	76	132	95	72	118	180
Fresh wt. roots other than white	893	1041	2804	2661	1689	1532	1926	3055
Dry wt. roots other than white	249	319	864	829	560	453	554	947
No. white roots	28	36	107	52	27	44	34	87
Fresh wt. white roots	447	465	1522	897	307	1027	410	1259
Dry wt. white roots	93	100	246	190	68	190	79	219
No. roots other than white per tiller	1.75	1.98	0.58	1.18	1.70	1.50	3.03	1.85
Dry wt. roots other than white per tiller	10.3	8.1	6.6	7.4	10.0	9.4	14.2	9.7
No. white roots per tiller	1.17	0.92	0.82	0.46	0.48	0.92	0.87	0.90
Dry wt. white roots per tiller	3.9	2.6	1.9	1.7	1.2	4.0	2.0	2.3
No. white roots as % no. total roots	40.0	31.9	58.5	28.3	22.1	37.9	22.4	32.6
Dry wt. white roots as % dry wt. total roots	27.2	23.9	22.1	18.7	10.8	29.6	12.5	18.8
D.M. % roots other than white	27.9	30.6	30.8	31.2	33.2	29.6	28.8	31.0
D.M. % white roots	20.8	21.5	16.2	21.2	22.2	18.5	19.3	17.4

APPENDIX 2. (Continued)

Individual plant root results: 10th lifting: 22/6/53.

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	65	81	95	86	67	65	153	101
No. roots other than white	219	253	309	268	176	219	296	255
Fresh. wt. roots other than white	6429	11144	9486	8875	8096	8061	8297	10348
Dry wt. roots other than white	1991	3361	3000	2763	2404	2472	2509	3055
No. white roots	18	17	37	24	19	14	58	39
Fresh wt. white roots	486	317	1035	1044	638	313	2481	1470
Dry. wt. white roots	125	64	225	244	108	69	471	311
No. roots other than white per tiller	3.37	3.13	3.25	3.12	2.63	3.37	1.93	2.52
Dry wt. roots other than white per tiller	30.7	41.5	31.6	32.2	25.9	38.0	16.4	30.3
No. white roots per tiller	0.28	0.21	0.39	0.28	0.28	0.22	0.38	0.39
Dry wt. white roots per tiller	1.9	0.8	2.4	2.8	1.6	1.1	3.1	3.1
No. white roots as % no. total roots	7.6	6.3	10.7	8.2	9.8	6.0	16.4	13.3
Dry wt. white roots as % dry wt. total roots	5.9	1.9	7.0	8.1	4.3	2.7	15.8	9.2
D.M. % roots other than white	31.0	30.2	31.6	31.1	29.7	30.7	30.2	29.5
D.M. % white roots	25.7	20.2	21.7	23.4	16.9	22.0	19.0	21.2

APPENDIX 2. (Continued)

Individual plant root results: 11th lifting: 13/7/53.

Species	Perennial ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	207	69	84	157	74	161	192	164
No. roots other than white	373	168	211	280	176	287	343	284
Fresh wt. roots other than white	7978	3632	3008	4105	3403	5880	10302	4978
Dry wt. roots other than white	2305	1062	952	1225	1036	1778	2854	1463
No. white roots	75	42	30	60	41	85	90	94
Fresh wt. white roots	1329	757	449	1413	689	1529	1827	1859
Dry wt. white roots	283	113	63	196	116	225	278	297
No. roots other than white per tiller	1.80	2.43	2.51	1.78	2.38	1.78	1.79	1.74
Dry wt. roots other than white per tiller	11.1	15.4	11.3	7.8	14.0	11.1	14.9	8.9
No. white roots per tiller	0.36	0.61	0.36	0.38	0.55	0.53	0.47	0.57
Dry wt. white roots per tiller	1.4	1.6	0.8	1.3	1.6	1.4	1.4	1.8
No. white roots as % no. total roots	16.7	20.0	12.4	17.7	18.9	22.8	20.8	24.8
Dry wt. white roots as % dry wt. total roots	10.9	9.6	6.2	13.8	10.1	11.2	8.9	16.9
D.M. % roots other than white	28.9	29.2	31.7	29.8	30.4	30.2	27.7	29.4
D.M. % white roots	21.3	14.9	14.0	13.9	16.8	14.7	15.2	16.0

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	Dead	Dead	118	162	40	104	159	Dead
No. roots other than white	-	-	89	281	49	177	291	-
Fresh wt. roots other than white	-	-	3689	5593	544	4494	6027	-
Dry wt. roots other than white	-	-	876	1251	153	1330	1706	-
No. white roots	-	-	141	185	45	126	140	-
Fresh wt. white roots	-	-	3774	5072	545	2153	2272	-
Dry wt. white roots	-	-	500	703	82	315	407	-
No. roots other than white per tiller	-	-	0.75	1.74	1.23	1.70	1.83	-
Dry wt. roots other than white per tiller	-	-	7.5	7.8	3.8	12.8	10.7	-
No. white roots per tiller	-	-	1.20	1.14	1.12	1.21	0.88	-
Dry wt. white roots per tiller	-	-	4.2	4.3	2.1	3.0	2.6	-
No. white roots as % no. total roots	-	-	61.3	39.7	47.9	41.5	32.5	-
Dry wt. white roots as % dry wt. total roots	-	-	36.3	36.0	34.9	19.2	19.3	-
D.M. % roots other than white	-	-	23.8	22.4	28.1	29.6	28.3	-
D.M. % white roots	-	-	13.3	13.9	15.1	14.6	17.9	-

APPENDIX 2. (Continued)

Individual plant roots results: 11th lifting: 13/7/53.

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	98	84	120	109	138	60	135	64
No. roots other than white	243	220	300	280	271	152	318	200
Fresh wt. roots other than white	9440	6339	10755	14510	10961	7148	12758	6402
Dry wt. roots other than white	2632	1884	3059	4021	3137	2101	3820	2042
No. white roots	52	54	40	72	66	35	62	37
Fresh wt. white roots	2130	1861	1640	4762	3238	1099	3291	1556
Dry wt. white roots	395	416	343	1032	594	236	758	337
No. roots other than white per tiller	2.48	2.62	2.50	2.57	1.96	2.54	2.36	3.12
Dry wt. roots other than white per tiller	27.0	22.4	25.5	36.9	22.7	35.0	28.3	31.9
No. white roots per tiller	0.53	0.64	0.33	0.66	0.48	0.58	0.46	0.58
Dry wt. white roots per tiller	4.0	5.0	2.9	9.5	4.3	3.9	5.6	5.3
No. white roots as % no. total roots	17.6	19.7	11.8	20.4	19.6	18.7	16.3	15.6
Dry wt. white roots as % dry wt. total roots	13.0	18.1	10.1	20.4	15.9	10.1	16.6	14.2
D.M. % roots other than white	27.9	29.7	28.4	27.7	28.6	29.4	29.9	31.9
D.M. % white roots	18.5	22.4	20.9	21.7	18.3	21.5	23.0	21.7

APPENDIX 2. (Continued)

Individual plant roots results: 12th lifting: 3/8/53.

Species	Perennial Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	149	110	183	209	86	133	177	119
No. roots other than white	409	301	385	487	174	197	388	146
Fresh wt. roots other than white	3769	3536	6241	7242	4023	2063	5193	2324
Dry wt. roots other than white	1073	1033	1825	2087	1258	659	1764	766
No. white roots	43	43	67	45	55	58	50	66
Fresh wt. white roots	635	780	1196	769	2148	876	1253	1777
Dry wt. white roots	97	108	194	93	296	125	246	248
No. roots other than white per tiller	2.75	2.73	2.10	2.33	2.02	1.48	2.20	1.23
Dry wt. roots other than white per tiller	7.2	9.4	10.0	10.0	14.7	5.0	10.0	6.4
No. white roots per tiller	0.29	0.40	0.37	0.22	0.64	0.44	0.28	0.55
Dry wt. white roots per tiller	0.7	1.0	1.0	0.4	3.4	0.9	1.4	2.1
No. white roots as % no. total roots	9.5	12.5	14.8	8.5	24.0	22.7	11.4	31.1
Dry wt. white roots as % dry wt. total roots	8.3	9.5	9.6	4.3	19.0	15.9	12.2	24.4
D.M. % roots other than white	28.5	29.2	29.2	28.8	31.3	31.9	34.0	33.0
D.M.% white roots	15.3	13.9	16.2	12.1	13.8	14.3	19.6	14.0

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	109	37	125	88	157	Dead	Dead	Dead
No. roots other than white	260	60	241	192	186	-	-	-
Fresh wt. roots other than white	2655	944	7285	4672	5838	-	-	-
Dry wt. roots other than white	829	244	1849	1179	1402	-	-	-
No. white roots	35	23	142	97	191	-	-	-
Fresh wt. white roots	405	536	4134	2854	4249	-	-	-
Dry wt. white roots	87	77	621	436	732	-	-	-
No. roots other than white per tiller	2.39	1.62	1.93	2.18	1.18	-	-	-
Dry wt. roots other than white per tiller	7.5	6.6	14.8	13.4	8.9	-	-	-
No. white roots per tiller	0.32	0.62	1.13	1.10	1.22	-	-	-
Dry wt. white roots per tiller	0.8	2.1	5.0	5.0	4.7	-	-	-
No. white roots as % no. total roots	11.9	27.7	37.1	33.5	50.7	-	-	-
Dry wt. white roots as % dry wt. total roots	9.6	24.0	25.1	27.0	34.4	-	-	-
D.M. % roots other than white	30.9	25.9	25.4	25.2	24.0	-	-	-
D.M. % white roots	21.5	14.4	15.0	15.3	17.2	-	-	-

APPENDIX 2. (Continued)

Individual plant root results: 12th lifting: 3/8/53.

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	101	62	25	90	66	101	151	37
No. tillers other than white	303	203	96	257	160	354	422	121
Fresh wt. roots other than white	8423	9130	5803	12294	5446	8703	13702	4937
Dry wt. roots other than white	2499	2820	1739	3798	1697	2550	3876	1418
No. white roots	33	26	6	39	6	42	63	3
Fresh wt. white roots	1224	1092	113	3684	121	2593	3221	12
Dry wt. white roots	226	209	38	640	15	545	557	5
No. roots other than white per tiller	3.00	3.28	3.84	2.86	2.43	3.50	2.79	3.28
Dry wt. roots other than white per tiller	24.8	45.5	69.5	42.2	25.8	25.2	25.7	38.4
No. white roots per tiller	0.33	0.42	0.24	0.43	0.09	0.42	0.42	0.08
Dry wt. white roots per tiller	2.2	3.4	1.5	7.1	0.2	5.4	3.7	0.1
No. white roots as % no. total roots	9.8	11.3	5.9	13.2	3.6	10.6	13.0	2.4
Dry wt. white roots as % dry wt. total roots	8.3	6.9	2.1	14.5	0.9	17.6	12.6	0.4
D.M. % roots other than white	29.7	30.7	30.0	30.9	31.2	29.3	28.3	28.7
D.M. % white roots	18.5	19.1	33.6	17.4	12.4	21.0	17.3	41.7

APPENDIX 2. (Continued)

Individual plant root results: 13th lifting: 24/8/53.

Species	Perennial Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	182	126	198	207	56	134	72	114
No. roots other than white	251	286	383	405	195	214	208	324
Fresh wt. roots other than white	4914	6161	8874	5501	4696	6925	3996	5117
Dry wt. roots other than white	1704	1873	2543	1680	1340	1844	1213	1362
No. white roots	15	21	57	65	20	41	25	77
Fresh wt. white roots	151	308	1150	1143	303	1021	365	1617
Dry wt. white roots	28	45	158	181	47	167	69	266
No. roots other than white per tiller	1.38	2.27	1.93	1.96	3.48	1.59	2.89	2.84
Dry wt. roots other than white per tiller	9.4	14.9	12.9	8.1	24.0	13.8	16.8	12.0
No. white roots per tiller	0.08	0.17	0.29	0.31	0.36	0.31	0.35	0.68
Dry wt. white roots per tiller	0.2	0.4	0.8	0.9	0.8	1.2	1.0	2.3
No. white roots as % no. total roots	5.6	6.8	13.0	13.8	9.3	16.1	10.7	19.2
Dry wt. white roots as % dry wt. total roots	1.6	2.3	5.9	9.7	3.4	8.3	5.4	16.4
D.M. % roots other than white	34.7	30.4	28.7	30.5	28.5	26.6	30.4	26.6
D.M. % white roots	18.5	14.6	13.7	15.8	15.5	16.4	18.9	16.5

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	135	Dead	83	141	105	161	35	65
No. roots other than white	266	-	241	211	186	183	82	222
Fresh wt. roots other than white	7379	-	5552	5709	5542	3837	955	4080
Dry wt. roots other than white	2081	-	1538	1656	1622	1102	314	1253
No. white roots	131	-	147	82	75	131	45	57
Fresh wt. white roots	2837	-	2849	1417	1741	1764	569	906
Dry wt. white roots	539	-	471	285	386	316	122	179
No. roots other than white per tiller	1.97	-	2.90	1.50	1.77	1.14	2.34	3.42
Dry wt. roots other than white per tiller	15.4	-	18.5	11.8	15.5	6.8	9.0	19.3
No. white roots per tiller	0.97	-	1.77	0.58	0.72	0.82	1.29	0.88
Dry wt. white roots per tiller	4.0	-	5.7	2.0	3.7	2.0	3.5	2.8
No. white roots as % no. total roots	33.0	-	37.9	28.0	28.7	41.7	35.4	20.4
Dry wt. white roots as % dry wt. total roots	20.6	-	23.4	14.7	19.2	22.3	28.0	12.5
D.M. % roots other than white	28.2	-	27.7	29.0	29.3	28.7	32.9	30.7
D.M. % white roots	19.0	-	16.5	20.1	22.2	17.9	21.4	19.8

APPENDIX 2. (Continued)

Individual plant root results: 13th lifting: 24/3/53.

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	121	75	97	32	59	102	64	196
No. roots other than white	220	175	227	91	179	183	151	190
Fresh wt. roots other than white	6169	6242	11443	3345	5146	5972	4420	8366
Dry wt. roots other than white	1952	2134	3519	1142	1701	1979	1353	2748
No. white roots	38	16	36	25	19	20	9	39
Fresh wt. white roots	1610	688	1743	1001	923	914	547	2424
Dry wt. white roots	293	125	396	226	171	185	113	535
No. roots other than white per tiller	1.82	2.34	2.34	2.84	3.04	1.79	2.36	0.97
Dry wt. roots other than white per tiller	16.2	28.4	36.3	35.7	28.9	19.4	21.1	14.1
No. white roots per tiller	0.31	0.21	0.37	0.78	0.32	0.20	0.14	0.20
Dry wt. white roots per tiller	2.4	1.7	4.1	7.1	2.9	1.8	1.8	2.7
No. white roots as % no. total roots	14.7	8.4	13.7	21.6	9.6	9.9	5.6	17.0
Dry wt. white roots as % dry wt. total roots	13.1	5.5	10.1	16.5	9.1	8.6	7.7	16.3
D.M. % roots other than white	31.6	34.2	30.8	34.1	33.1	33.1	30.6	32.9
D.M. % white roots	18.2	18.2	22.7	22.6	18.5	20.2	20.7	22.1

APPENDIX 2. (Continued)

Individual plant root results: 14th lifting: 14/9/53.

Species	Perennial Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	78	55	80	84	43	110	58	77
No. roots other than white	244	158	185	261	131	131	193	71
Fresh wt. roots other than white	5184	2991	3195	6334	1584	3069	1170	941
Dry wt. roots other than white	1697	990	991	1976	585	1031	438	314
No. white roots	52	20	21	32	16	34	16	21
Fresh wt. white roots	1316	414	536	942	275	610	370	391
Dry wt. white roots	211	84	119	167	36	86	65	56
No. roots other than white per tiller	3.13	2.88	2.31	3.11	3.05	1.19	3.33	0.92
Dry wt. roots other than white per tiller	21.8	18.0	12.4	23.5	13.6	9.4	7.6	4.1
No. white roots per tiller	0.66	0.36	0.26	0.38	0.37	0.31	0.28	0.27
Dry wt. white roots per tiller	2.6	1.5	1.5	2.0	0.8	0.8	1.1	0.7
No. white roots as % no. total roots	17.6	11.2	10.2	10.9	10.9	20.6	7.7	22.8
Dry wt. white roots as % dry wt. total roots	11.1	7.8	10.7	7.8	5.8	7.7	12.9	15.2
D.M. % roots other than white	32.7	33.1	31.0	31.2	36.9	33.6	37.4	33.4
D.M. % white roots	16.0	20.3	22.2	17.7	13.1	14.1	17.6	14.3

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	42	55	Dead	Dead	17	20	192	67
No. roots other than white	76	97	-	-	47	43	287	151
Fresh wt. roots other than white	2346	1465	-	-	1021	724	7840	3896
Dry wt. roots other than white	750	462	-	-	360	214	2228	1092
No. white roots	67	38	-	-	14	19	204	69
Fresh wt. white roots	1432	783	-	-	171	497	2898	1055
Dry wt. white roots	331	169	-	-	46	101	596	252
No. roots other than white per tiller	1.81	1.76	-	-	2.77	2.15	1.50	2.25
Dry wt. roots other than white per tiller	17.9	8.4	-	-	21.2	10.7	11.6	16.3
No. white roots per tiller	1.59	0.69	-	-	0.82	0.95	1.06	1.03
Dry wt. white roots per tiller	7.9	3.1	-	-	2.7	5.1	3.1	3.8
No. white roots as % no. total roots	46.8	28.2	-	-	23.0	30.6	40.5	31.4
Dry wt. white roots as % dry wt. total roots	30.6	26.8	-	-	11.3	32.1	21.1	18.8
D.M. % roots other than white	32.0	31.5	-	-	35.3	29.6	28.4	28.0
D.M. % white roots	23.1	21.6	-	-	26.9	20.3	20.6	23.9

APPENDIX 2. (Continued)

Individual plant root results: 14th lifting: 14/9/53.

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	74	75	84	78	55	55	81	101
No. roots other than white	251	216	233	200	185	114	263	282
Fresh wt. roots other than white	7172	9620	7577	6000	5468	4016	7971	12671
Dry wt. roots other than white	2441	3235	2514	1924	1975	1450	2805	4077
No. white roots	20	59	53	44	20	24	43	53
Fresh wt. white roots	332	3095	1406	2116	1105	932	942	2116
Dry wt. white roots	53	729	240	399	232	143	151	446
No. roots other than white per tiller	3.39	2.87	2.77	2.57	3.37	2.07	3.25	2.80
Dry wt. roots other than white per tiller	33.0	43.2	29.9	24.7	35.9	26.4	34.6	40.4
No. white roots per tiller	0.27	0.79	0.63	0.56	0.36	0.44	0.53	0.52
Dry wt. white roots per tiller	0.7	9.7	2.9	5.1	4.2	2.6	1.9	4.4
No. white roots as % no. total roots	7.4	21.4	18.5	18.0	9.8	17.4	14.0	15.8
Dry wt. white roots as % dry wt. total roots.	2.1	18.4	8.7	17.2	10.5	9.0	5.1	9.9
D.M. % roots other than white	34.0	33.6	33.2	32.1	36.1	36.1	35.2	32.2
D.M. % white roots	16.0	23.6	17.1	18.9	21.0	15.3	16.0	21.1

APPENDIX 2. (Continued)

Individual plant root results: 15th lifting: 5/10/53.

Species	Perennial Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	65	159	188	161	124	70	92	165
No. roots other than white	223	396	377	391	361	223	169	398
Fresh wt. roots other than white	2906	8878	4628	6839	8670	3525	1830	9778
Dry wt. roots other than white	983	2738	1491	2169	2776	1117	608	3250
No. white roots	14	29	32	22	37	46	10	60
Fresh wt. white roots	218	756	534	525	771	361	156	1238
Dry wt. white roots	49	153	114	120	178	230	36	318
No. roots other than white per tiller	3.43	2.50	2.01	2.43	2.91	3.18	1.84	2.41
Dry wt. roots other than white per tiller	15.1	17.2	7.9	13.5	22.4	16.0	6.6	19.7
No. white roots per tiller	0.22	0.18	0.17	0.14	0.30	0.66	0.11	0.36
Dry wt. white roots per tiller	0.8	0.1	0.6	0.7	1.4	3.3	0.4	1.9
No. white roots as % no. total roots	5.9	6.8	7.8	5.3	9.3	17.1	5.6	13.1
Dry wt. white roots as % dry wt. total roots	4.7	5.3	7.1	5.2	6.0	17.1	5.6	8.9
D.M. % roots other than white	33.8	30.8	32.2	31.7	32.0	31.7	33.2	33.2
D.M. % white roots	22.5	20.2	21.4	22.9	23.1	26.7	23.1	25.7

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	54	22	Dead	67	83	35	38	105
No. roots other than white	157	40	-	156	293	113	164	301
Fresh wt. roots other than white	5842	817	-	5962	6539	1202	1353	6909
Dry wt. roots other than white	2159	306	-	1955	2282	486	537	2181
No. white roots	42	27	-	47	67	10	11	30
Fresh wt. white roots	964	421	-	808	1049	66	119	335
Dry wt. white roots	239	85	-	201	286	11	28	85
No. roots other than white per tiller	2.90	1.82	-	2.33	3.53	3.23	4.31	2.86
Dry wt. roots other than white per tiller	40.0	13.9	-	29.2	27.5	13.9	14.1	20.8
No. white roots per tiller	0.78	1.23	-	0.70	0.81	0.29	0.29	0.29
Dry wt. white roots per tiller	4.4	3.9	-	3.0	3.4	0.3	0.7	0.8
No. white roots as % no. total roots	21.1	40.3	-	23.2	18.6	8.2	6.3	9.1
Dry wt. white roots as % dry wt. total roots	10.0	21.8	-	9.3	11.6	2.2	5.0	3.8
D.M. % roots other than white	37.0	37.5	-	32.8	34.9	40.4	39.7	31.6
D.M. % white roots	24.8	20.2	-	24.9	27.3	16.7	23.5	25.4

APPENDIX 2. (Continued)

Individual plant root results: 15th lifting: 5/10/53.

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	74	91	81	118	47	74	79	163
No. roots other than white	169	194	205	308	128	175	249	320
Fresh wt. roots other than white	4774	8025	5501	12623	3405	4368	11535	11333
Dry wt. roots other than white	1609	2936	1960	4410	1166	1505	3852	3628
No. white roots	43	49	24	43	13	36	28	44
Fresh wt. white roots	1095	2079	883	1708	417	1793	1830	1456
Dry wt. white roots	259	460	159	418	104	423	414	324
No. roots other than white per tiller	2.29	2.13	2.53	2.61	2.72	2.36	3.16	1.97
Dry wt. roots other than white per tiller	21.7	32.2	24.2	37.4	24.8	20.4	48.8	22.2
No. white roots per tiller	0.58	0.54	0.30	0.36	0.28	0.49	0.35	0.27
Dry wt. white roots per tiller	3.5	5.1	2.0	3.5	2.2	5.7	5.2	2.0
No. white roots as % no. total roots	20.3	20.2	10.5	12.3	9.2	17.1	10.1	12.1
Dry wt. white roots as % dry wt. total roots	13.9	13.5	7.5	8.7	8.2	21.9	9.7	8.2
D.M. % roots other than white	33.7	36.6	35.6	34.9	34.2	34.5	33.4	32.0
D.M. % white roots	23.7	22.1	18.0	24.5	24.9	23.6	22.6	22.3

APPENDIX 2. (Continued)

Individual plant root results: 16th lifting: 27/10/53.

Species	Perennial Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	44	78	89	93	41	85	94	70
No. roots other than white	168	214	360	391	170	275	359	260
Fresh wt. roots other than white	1474	3208	5386	4438	1411	3737	3857	2994
Dry wt. roots other than white	561	1203	1904	1544	506	1129	1319	1026
No. white roots	19	8	8	9	11	22	18	4
Fresh wt. white roots	92	65	56	90	101	170	96	15
Dry wt. white roots	24	9	10	17	22	38	25	6
No. roots other than white per tiller	3.82	2.74	4.04	4.20	4.15	3.24	3.82	3.72
Dry wt. roots other than white per tiller	12.8	15.4	21.4	16.6	12.3	13.3	14.0	14.7
No. white roots per tiller	0.43	0.10	0.09	0.10	0.27	0.26	0.19	0.06
Dry wt. white roots per tiller	0.5	0.1	0.1	0.2	0.5	0.4	0.3	0.1
No. white roots as % no. total roots	10.2	3.6	2.2	2.2	6.1	7.4	4.8	1.5
Dry wt. white roots as % dry wt. total roots	4.1	0.7	0.5	1.1	4.2	3.3	1.9	0.6
D.M. % roots other than white	38.1	37.5	35.4	34.8	35.9	30.2	34.2	34.3
D.M. % white roots	26.1	13.9	17.9	18.9	21.8	22.4	26.0	40.0

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	31	157	21	113	16	103	37	87
No. roots other than white	151	491	100	342	129	347	122	265
Fresh wt. roots other than white	1921	6302	689	4268	1010	5794	1807	5606
Dry wt. roots other than white	727	2135	265	1605	391	2075	665	1886
No. white roots	8	18	3	17	-	5	4	21
Fresh wt. white roots	58	97	21	87	-	48	27	90
Dry wt. white roots	12	28	4	28	-	12	5	28
No. roots other than white per tiller	4.87	3.13	4.76	3.03	8.06	3.37	3.30	3.05
Dry wt. roots other than white per tiller	23.4	13.6	12.6	14.2	24.4	20.1	18.0	21.7
No. white roots per tiller	0.26	0.11	0.14	0.15	-	0.05	0.11	0.24
Dry wt. white roots per tiller	0.4	0.2	0.2	0.2	-	0.1	0.1	0.3
No. white roots as % no. total roots	5.0	3.5	2.9	4.7	-	1.4	3.2	7.3
Dry wt. white roots as % dry wt. total roots	1.6	1.3	1.5	1.7	-	0.6	0.6	1.5
D.M. % roots other than white	37.8	33.9	38.5	37.6	38.7	35.8	36.8	33.6
D.M. % white roots	20.7	28.9	19.1	32.2	-	25.0	18.5	31.1

APPENDIX 2. (Continued)

Individual plant root results: 16th lifting: 27/10/53

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	66	87	109	42	43	102	61	156
No. roots other than white	232	277	359	264	241	334	373	453
Fresh wt. roots other than white	5005	10633	10094	4884	7782	9061	10756	13258
Dry wt. roots other than white	1612	3494	3200	1682	2358	3038	3428	4546
No. white roots	34	32	16	22	8	32	34	39
Fresh wt. white roots	768	1449	732	825	289	1000	1034	1614
Dry wt. white roots	224	385	179	218	64	232	243	460
No. roots other than white per tiller	3.52	3.18	3.29	6.29	5.61	3.28	6.12	2.91
Dry wt. roots other than white per tiller	24.4	40.2	29.4	40.1	54.9	29.8	56.2	29.1
No. white roots per tiller	0.52	0.37	0.15	0.52	0.19	0.31	0.56	0.25
Dry wt. white roots per tiller	3.4	4.4	1.6	5.2	1.5	2.3	4.0	3.0
No. white roots as % no. total roots	12.8	10.3	4.3	7.7	3.2	8.7	[illegible].4	7.9
Dry wt. white roots as % dry wt. total roots	12.2	9.9	5.3	11.5	2.6	7.1	6.6	9.2
D.M. % roots other than white	32.2	32.9	31.7	34.4	30.3	33.5	31.9	34.3
D.M. % white roots	29.2	26.6	24.5	26.4	22.2	23.2	23.5	28.5

APPENDIX 2. (Continued)

Individual plant root results: 17th lifting: 16/11/53.

Species	Perennial Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	74	88	70	110	89	79	92	73
No. roots other than white	293	310	303	249	219	266	227	190
Fresh wt. roots other than white	3319	4619	4349	3658	2992	5358	1953	3178
Dry wt. roots other than white	1216	1730	1588	1323	1086	1768	708	1179
No. white roots	11	3	3	3	1	5	3	4
No. roots other than white per tiller	3.96	3.52	4.33	2.26	2.46	3.37	2.47	2.61
Dry wt. roots other than white per tiller	16.4	19.7	22.7	11.9	12.2	22.4	7.7	16.2
No. white roots per tiller	0.16	0.03	0.04	0.03	0.01	0.06	0.03	0.05
No. white roots as % no. total roots	3.6	1.0	1.0	1.2	0.5	1.8	1.3	2.1
D.M. % roots other than white	36.6	37.5	36.5	36.2	36.3	33.0	36.3	37.1

Species	Italian Ryegrass							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	27	21	Dead	18	7	32	48	44
No. roots other than white	104	70	-	69	22	66	129	113
Fresh wt. roots other than white	2721	1152	-	1617	134	893	1964	3982
Dry wt. roots other than white	981	420	-	628	50	282	668	1238
No. white roots	9	6	-	-	4	8	16	16
No. roots other than white per tiller	3.86	3.33	-	3.84	3.14	2.06	2.69	2.57
Dry wt. roots other than white per tiller	36.3	20.0	-	34.8	7.1	8.8	13.9	28.2
No. white roots per tiller	0.33	0.29	-	-	0.57	0.25	0.33	0.36
No. white roots as % no. total roots	8.0	7.9	-	-	15.4	10.8	11.0	12.4
D.M. % roots other than white	36.1	36.5	-	38.8	37.3	31.6	34.0	31.1

APPENDIX 2. (Continued)

Individual plant root results: 17th lifting: 16/11/53.

Species	Tall Fescue							
Plant No.	1	2	3	4	5	6	7	8
No. tillers	76	108	53	57	108	108	81	60
No. roots other than white	194	278	213	226	321	277	242	203
Fresh wt. roots other than white	6829	9666	9756	10205	10640	10856	11034	6084
Dry wt. roots other than white	2241	3184	3110	3109	3328	3268	3348	1996
No. white roots	4	3	6	8	-	8	6	-
No. roots other than white per tiller	2.55	2.57	4.02	3.96	2.97	2.57	2.99	3.38
Dry wt. roots other than white per tiller	29.4	29.5	58.7	54.5	30.8	30.3	41.4	33.3
No. white roots per tiller	0.06	0.03	0.11	0.14	-	0.07	0.07	-
No. white roots as % no. total roots	2.0	1.1	2.7	3.4	-	2.8	2.4	-
D.M. % roots other than white	32.8	32.9	31.9	30.5	31.3	30.1	30.3	32.8

APPENDIX 3.

Weather data, Grasslands Division Meteorological Station

Week Ending	Rain ins.	Evaporation ins.	Temperatures °F. Grass min.	Soil 4"	Soil 12"	Sun hours
26th Aug. 1952	-	0.570	32.9	44.8	48.5	63.9
2nd September	0.91	0.632	38.8	48.1	50.1	22.4
9th September	0.06	0.241	39.7	48.9	50.9	19.1
16th September	0.19	0.494	44.7	52.5	53.6	28.8
23rd September	0.28	0.587	40.7	52.9	54.9	36.1
30th September	0.15	0.683	36.9	50.4	53.8	41.1
7th October	0.71	0.568	43.1	53.7	55.2	21.1
14th October	0.25	0.320	46.1	55.6	57.4	38.4
21st October	0.72	0.740	45.4	57.8	59.1	28.9
28th October	0.13	0.872	41.2	56.0	58.6	62.9
4th November	1.35	0.338	53.0	60.1	62.3	13.6
11th November	3.68	0.748	48.2	58.7	60.8	31.4
18th November	0.70	0.457	49.3	59.7	61.6	38.8
25th November	1.04	0.878	45.1	57.4	60.4	22.9
2nd December	1.68	0.752	52.3	59.2	61.1	18.4
9th December	1.56	0.846	51.9	61.9	63.7	33.4
16th December	0.47	0.806	51.9	61.9	64.1	37.4
23rd December	1.28	1.811	52.6	62.4	64.1	32.5
30th December	-	1.026	52.5	65.2	66.4	40.9
6th Jan. 1953	1.24	0.987	53.7	62.9	65.3	15.8
13th January	1.59	1.383	49.6	65.1	66.8	55.0
20th January	0.14	1.028	45.7	61.4	64.4	46.8
27th January	6.67	0.788	49.7	63.3	66.2	23.3
3rd February	0.42	0.942	52.5	62.5	64.5	38.1
10th February	0.17	0.738	53.1	66.3	67.5	38.2
17th February	2.02	0.583	55.4	63.7	66.4	26.3
24th February	0.51	0.719	50.7	60.9	64.1	32.4
3rd March	0.10	0.598	52.4	62.3	64.4	29.1
10th March	0.06	0.947	49.3	62.2	64.8	50.2
17th March	0.35	0.851	46.7	60.8	63.5	40.9
24th March	0.30	0.544	49.5	61.9	63.8	33.3
31st March	0.70	0.610	48.2	60.1	62.9	30.0
7th April	1.35	0.434	46.8	56.3	59.2	13.1
14th April 1953	0.44	0.453	41.7	53.2	56.6	18.6
21st April	0.55	0.375	42.5	53.5	56.2	32.3
28th April	0.31	0.292	45.5	55.5	58.0	34.5
5th May	1.15	0.379	44.3	55.1	57.6	29.7
12th May	0.80	0.272	45.5	54.2	56.2	15.0
19th May	1.14	0.252	35.5	48.3	52.4	16.8
26th May	0.70	0.179	37.6	47.7	50.4	22.0
2nd June	0.66	0.172	36.2	48.2	51.2	22.3
9th June	0.33	0.192	35.0	47.3	50.6	22.5
16th June	1.26	0.100	42.9	50.2	51.3	5.5
23rd June	0.37	0.187	38.2	47.3	50.0	4.9
30th June	0.58	0.211	29.5	42.8	47.2	21.4
7th July	1.18	0.121	35.7	44.8	46.7	24.4
14th July	1.19	0.193	30.3	43.6	47.2	26.0
21st July	0.51	0.221	29.1	42.9	45.3	20.6
28th July	0.17	0.196	31.8	44.4	47.0	25.7
4th August	0.01	0.160	26.2	41.4	44.5	28.0
11th August	0.44	0.186	30.5	44.2	46.6	30.4
18th August	1.08	0.208	37.7	47.7	48.6	18.3
25th August	0.07	0.319	28.9	43.8	47.6	39.6
1st September	0.31	0.382	37.2	47.3	48.7	22.0
8th September	1.65	0.270	43.6	51.5	51.6	17.5
15th September	1.51	0.334	39.8	50.6	52.5	24.8
22nd September	0.04	0.411	32.5	49.5	51.9	50.1
29th September	0.21	0.613	37.0	51.7	53.9	42.0
6th October	1.29	0.390	38.9	51.0	52.7	18.5
13th October	2.42	0.262	41.3	53.5	54.5	19.7
20th October	0.13	0.593	36.9	52.2	54.4	22.3
27th October	1.19	0.907	39.5	56.0	57.3	55.0
3rd November	0.56	0.879	45.1	59.9	60.9	56.8
10th November	2.28	0.696	49.7	61.4	62.7	22.9
16th November	0.53	0.667	42.2	57.4	59.6	27.4

APPENDIX 4.

Flowering behaviour in the three grass species.

Emerging flower-heads were first seen in perennial ryegrass at the cut on 13th November, in tall fescue on 11th December, and in Italian ryegrass on 22nd December. A record was kept at each cutting date of all individual plants showing flower-heads, until the final appearance in tall fescue on 20th May.

The first table sets out the number of plants cut, the number of plants showing flowerheads, and the percentage of plants cut which were flowering. This last figure is the correct basis for comparisons between the species, since blocks were being lifted for root examinations over this period, and the number of plants cut, was decreasing at intervals.

APPENDIX 4. (Continued) Percentage of Plants Flowering at Each Cutting Date.

Cutting date.	Perennial Ryegrass			Italian Ryegrass			Tall Fescue		
	No. plants cut	No. plants flowering	% plants flowering	No. plants cut	No. plants flowering	% plants flowering	No. plants cut	No. plants flowering	% plants flowering
13th November, 1952.	136	5	3.7	-	-	-	-	-	-
28th November	136	32	23.5	-	-	-	-	-	-
11th December	128	40	31.3	-	-	-	128	58	45.3
22nd December	128	40	31.3	117	9	7.7	128	45	35.2
6th January, 1953.	120	52	43.3	109	52	47.7	120	50	41.7
21st January	120	36	30.0	109	42	38.5	120	33	27.5
4th February	112	3	2.7	100	2	2.0	112	28	25.0
18th February	104	2	1.9	96	3	3.1	104	19	18.3
4th March	-	-	-	-	-	-	104	15	14.4
18th March	-	-	-	-	-	-	96	9	9.4
2nd April	-	-	-	-	-	-	88	21	23.9
16th April	-	-	-	-	-	-	88	11	12.5
4th May	-	-	-	-	-	-	80	8	10.0
20th May	-	-	-	-	-	-	72	3	4.2

In both ryegrass species, there is one cutting date at the commencement of flowering where less than 10% of the number of plants cut had actually emergent flower-heads. The percentage of plants flowering rose sharply at the second cut, especially in Italian ryegrass where nearly half of the plants possessed flower-heads; retained a fairly high flowering rate until late in January; and then tailed off to low flowering percentages during the two cutting dates in February. The percentage number of plants flowering was about 25% or more over 5 cutting dates (28th November to 21st January inclusive) in perennial ryegrass, and over 2 cutting dates (6th January to 21st January inclusive) in Italian ryegrass.

In tall fescue, there is a sudden appearance of flower-heads in 45% of the plants at the top cut on 11th December, so that this species differs from the ryegrasses. The percentage number of plants flowering thereafter continues at more than 25% for the next 4 cuttings, up to and including that on 4th February. From the cut on 18th February up to and including that on 4th May, flowering in tall fescue was still substantial, the percentage number of plants with flowerheads at each of these 6 cutting dates being between 10% and 20% (with the exceptions of 9.4% on 18th March, and an unexplained recovery to 23.9% on 2nd April.) The final appearance of flowerheads in tall fescue was at the low level of 4.2% on the 20th May. The interesting feature of the table is that flowerhead emergence in tall fescue continued for six cutting dates subsequent to cessation of flowering in both ryegrasses.

The second table is designed to give some idea of the earliness or lateness of flowering in each species. This is attempted by making a division as nearly as possible at the centre of the flowering range for each species, and to count the number of plants with emergent seedheads on each side of this division.

Periods and number of plants with flowerheads.

Species	Early flowering		Late flowering	
	Period	No. of plants	Period	No. of plants
Perennial ryegrass	13th Nov - 22nd Dec.	117	6th Jan - 18th Feb.	93
Italian ryegrass	22nd Dec - 6th Jan.	61	21st Jan - 18th Feb.	47
Tall fescue	11th Dec - 21st Jan.	186	4th Feb - 20th May	114

In each species, more flowering occurred in the early group, than in the late group. This is particularly marked in tall fescue, where large numbers of plants possessed emergent flower-heads at the cutting dates immediately following the first appearance of flowering.

A more detailed analysis of flowering behaviour was made on an individual plant basis, from the records which were kept for every plant at each cutting date. Plants in the first and second lifting blocks are omitted from this analysis, since these plants were removed from the experiment too early to gain any knowledge of flowering from them. The inclusion of the third and fourth lifting blocks may have introduced small errors into the analysis, particularly in tall fescue, since plants may have been removed before their flowering pattern was completed.

The results of this analysis are presented in the third table.

Analysis of flowering patterns in individual plants.

Group description	Number of plants		
	Ba	Bb	Bn
Never flowered	39	45	14
Flowerheads once, early	13	21	19
Flowerheads twice, early	6	1	22
Flowerheads, 3 or more times, early	-	-	12
Flowerheads once, late	16	10	9
Flowerheads twice, late	2	-	3
Flowerheads, 3 or more times, late	1	-	-
Flowerheads, once early and once late	9	29	8
Flowerheads, 3 times, early and late	13	5	9
Flowerheads, 4 times, early and late	11	-	10
Flowerheads, 5 times, early and late	9	-	5
Flowerheads, 6 times, early and late	1	-	5
Flowerheads, more than 6 times early and late	-	-	4

This table, together with the preceding table, clearly shows the greater amount of flowering which occurred in tall fescue, and the lesser amount in Italian ryegrass, in comparison with the intermediate flowering behaviour of perennial ryegrass. This is in keeping with the duration of flowering in each species. Thus the second table reveals that flowerheads were recorded on 300 occasions in tall fescue, on 210 occasions in perennial ryegrass, and in 108 cases with Italian ryegrass. The third table reveals that only 14 plants of tall fescue never flowered, whereas 39 perennial ryegrass and 45 Italian ryegrass plants never possessed emergent flowerheads. There were 45 tall fescue plants which flowered at 3 or more cutting dates, while 35 perennial ryegrass and only 5 Italian ryegrass plants flowered on 3 or more occasions.

The behaviour of the two ryegrass strains in this experiment - both strains being of New Zealand selected origin - does not accord with a conclusion reached by Cooper and Saeed (1949) in a study of the relationship between the annual habit and head production under various cutting systems. Four strains of perennial ryegrass (S.23, S.24, S.101 and Irish commercial) were employed in their study, together with commercial Italian ryegrass from Northern Ireland. They stated: "In the annual and biennial, (the young apices of the side-tillers) become 'ripe to flower' very rapidly, and will have developed heads before the next cut. Head production may thus continue throughout the season. A fortnightly cutting interval is just on the threshold for head production in Italian ryegrass........ In the perennial strains, the young shoots take longer to become 'ripe to flower' and consequently few heads are produced even with a monthly cutting interval."

The information in flowerhead emergence gained in the present experiment is not capable of further satisfactory analysis. However, the behaviour of the New Zealand ryegrass strains, and especially that of the Italian ryegrass, when considered in conjunction with the conclusions reached above with British material under, of course, very different experimental conditions, indicates that study of flowering behaviour in the local strains is unlikely to repeat results obtained elsewhere.

APPENDIX 5.

Sub-trial with Poa annua.

The original Poa annua plants failed to survive the cutting treatment imposed, and this species was therefore discarded from the main experiment. The plants contained in the first two lifting blocks were raised, and the root systems examined both visually and with tetrazolium. There was no indication of any tissue staining with tetrazolium salt, while the roots were very tender to the touch. Pipes still remained in the ground in the original 3rd to 16th lifting blocks inclusive, and it was decided to replant these with Poa annua, and follow their root behaviour over a shorter period.

Fresh seed was put into seedboxes in the glasshouse on 3rd June, 1953, and seedling plants, selected for uniformity of size and apparent vigour, were transplanted to the pipes on 26th June, 1953. A fresh allocation of random lifting numbers was made, and is given by the figure in brackets over the Poa annua pipes in the layout plan (Figure 1). Establishment of these plants was successful, and only one plant in the 13th block died.

The first top cut was taken on 14th August, all tissue being removed at a length of one inch from the crown of the plant, and further top cuts were made on 3 subsequent dates. Flowering was profuse at the cut on 8th September, and all plants carried flowerheads over the final two cutting dates. The herbage yields (leaf plus flowering tissue) are set out in the first table.

Results of top cut treatment in Poa annua sub-trial.

	No. of plants cut	Green-weight of herbage (gms.)	Dry-matter of herbage (%)	Dry-weight of herbage (gms)	Dry-weight of herbage per plant per day (mgm)
14th August	104	94.9	30.1	28.56	-
8th September	80	109.5	27.0	29.57	14.8
23rd September	64	93.9	25.3	23.76	24.6
19th October	40	136.8	26.2	35.81	34.6

It can be seen from this table that herbage production was proceeding at appreciable levels during the spring, and that by the final cutting date, there was no evidence of a decline in the rate of herbage growth.

The first root block lifting was made on 3rd August, by which time all plants were making obvious growth; the second and third liftings were made at fortnighly intervals; and subsequent liftings were made at weekly intervals until completion of the trial on 16th November, 1953. The results of the observations made on the root systems are presented in the second table.

Results of root observations in Poa Annua sub-trial

Date of lifting	3 Aug.	17 Aug.	31 Aug.	7 Sept.	14 Sept	21 Sept.	28 Sept.	5 Oct.	12 Oct.	19 Oct.	27 Oct.	2 Nov.	9 Nov.	16 Nov.
No. of plants lifted	8	8	8	8	8	8	8	8	8	8	8	8	7	8
No. of tillers per plant	44.9	49.8	55.6	63.1	48.4	60.5	77.1	37.1	44.5	76.4	86.1	46.5	45.7	71.1
No. of roots per plant	88.1	109.1	102.1	111.9	101.8	149.0	183.8	116.0	121.3	217.8	197.3	177.8	137.4	199.5
Fresh wt. roots per plant, mgm.	1611	2368	2052	2503	2178	1835	2329	2401	2048	3406	2123	1964	1397	1360
Dry wt. roots per plant, mgm.	294	472	502	609	596	527	706	664	591	1031	713	663	498	459
No. of roots per tiller	1.96	2.19	1.84	1.77	2.10	2.46	2.38	3.12	2.27	2.88	2.29	3.82	3.01	2.80
Dry wt. roots per tiller, mgm.	6.5	9.5	9.0	9.7	12.3	8.7	9.1	17.9	13.3	13.6	8.3	14.3	10.9	6.5
Dry wt. per root, mgm.	3.3	4.3	4.9	5.4	5.9	3.5	3.8	5.7	4.9	4.7	3.6	3.7	3.6	2.3
Dry matter % of roots	18.2	19.9	24.5	24.4	27.4	28.8	30.3	27.7	28.9	30.3	33.6	33.8	35.7	33.8

The results given in the table are average values, calculated over the number of plants included in each lifting block. The actual figures were rather variable, and little information could be derived from a statistical examination of this data, which covers such a short time interval. The main use, and hence the reason for the inclusion of this information as an appendix, is to record values found, under the conditions of the trial, for several plant characters in this species. Such information is not available from any other source.

Only one class of roots was recognized. The period during which observations were made on the root systems was apparently too short for ageing effects to show in the early-formed roots. No evidence of cortex deterioration was seen.

Two points are worthy of mention. Firstly, a comparison of the dry weights of the root systems (per plant, per tiller and per root) of these vigorously growing, young Poa annua plants with the equivalent dry weights for the species studied in the main experiment, shows that Poa annua has a well-developed root system. This root growth occurs at an early stage, and the proportion of root to top growth in Poa annua is of the same order as that in the longer-lived rye-grasses and tall fescue. This factor suggests that if the root system is involved in the ephemeral life-cycle of Poa annua, it is some quality of the roots themselves, rather than the amount of root tissue, which should be looked for in any explanation. Secondly, in both top growth and roots, the dry matter percentage in Poa annua is higher than in the other experimental species.