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SEASONAL ROOT CHANGES AND THEIR RELATIONSHIPS
TO LEAF PRODUCTION AND PERSISTENCY OF
GROWTH IN SOME GRASSES AND CLOVERS.

D. E. YEN.

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SECTION I.INTRODUCTION.

The seasonal behaviour of pasture plant species is of fundamental importance to the farmer as one of the indices of value of any particular species, and the uses to which it can be put; and to the plant breeder, since it is his primary object to produce pasture plants which suit the farmer under his particular system of farming. To illustrate this point specifically, the example of the ideals aimed at in the breeding of short rotation ryegrass in New Zealand may be cited. Quoting Levy (1945), "... Italian ryegrass is a one- to two-year plant for the temporary pasture, and the true perennial ryegrass can be used widely in rotational and permanent pastures. There is, however, too large a gap between true perennial ryegrass and true Italian ryegrass, and many years of breeding and selection within these species accentuated the gap rather than reduced it." It can be seen that the short rotation system of farming, incorporating pasture leys of 3-4 years was not well served in the choice of a suitable ryegrass. Thus the plant breeding section of the Grasslands Division (Department of Scientific and Industrial Research) turned its attention towards breeding by hybridisation of perennial and Italian ryegrass, a type that would possess as far as possible the desirable qualities of these two species in combination; that is, it would combine some of the rapid establishment, high winter and early spring growth and palatability of Italian ryegrass with an appreciable degree of persistency of perennial ryegrass. Seasonal growth thus played the major part in the objectives of the resultant programme from which short rotation ryegrass was produced. Comparative trials of yields of the three grasses, perennial, Italian and short rotation ryegrasses were conducted in different localities, serving a very important purpose in providing farmers with direct information regarding the seasonal characteristics of production of the new type. These trials, which are continuing, show that short rotation ryegrass conforms largely to the objectives aimed at, so that the requirements of the man farming under short rotation system have been met, to a great extent, by the work of the plant breeder.

While the result of any breeding project like the one described may be economically satisfactory, little knowledge is

gained of the nature of these seasonal growth changes effected by breeding. The information regarding this is restricted to the foliage growth in terms of single plant observations during the progeny testing part of the breeding programme, and dry matter figures obtained from yield trials of the resultant product. Thus there arises a situation where a result is obtained with little reference to the cause.

Hutchinson (1939) has stressed the need for increased knowledge of the physiological processes of plants if progress is to be made in breeding by improvement of methods of selection for quantitative characters. If this is true, more emphasis must be placed on investigations of the pasture plant as a physiological whole, whose seasonal growth is the result of the interaction of many environmental factors on the entire plant, root and above-ground parts.

It is at this point, that the present investigation hopes to supply some of the facts which link up seasonal production of grasses with one of the factors which, it would not be unreasonable to speculate, may be directly concerned, namely, seasonal root growth. It is only comparatively recently that American workers have investigated this aspect of root development, using as experimental material both cultivated species and indigenous prairie grasses, the latter being easier to handle due to the relative thickness of the individual roots. There is a paucity of New Zealand work on root development of pasture plants, Jacques being the only worker to concentrate on the subject. No results of seasonal studies of root growth of grasses in use in New Zealand have been published, while such studies of clovers have been neglected both here and overseas.

The role of the root system cannot be divorced from any consideration of the seasonal growth of plants, since its physiological functions of absorption, transport and storage of nutrients so important to the plant, are so closely bound up with any changes which may occur in the top-growth of the plants. Thus this study entails the description of root changes such as weight, new growth, degeneration of older roots, colour, etc., with the seasons, and where possible, measurements of the same. In this respect, the objects of the work are somewhat ahead of New Zealand studies of above ground parts of pasture plants. Corkill (1947) in a paper read to the Genetics Discussion Group, Massey College,

stated that more would have to be known of such considerations of leaf growth as morphological leaf characters, amount of tillering and seasonal influences, for improvement of selection methods in breeding, since yields from experimental plots by weight and individual plant observations without detailed descriptions were the only bases on which the pasture plant breeder worked in synthesizing new types.

Again, it appears that the plant is considered merely in terms of the green matter it produces, without cognizance of the fact that the physiological processes that govern the growth of leaf, and the conditions which modify those processes must act in some way on the rest of the plant. This investigation hopes to show the influence of season on the growth and behaviour of the underground portions of various pasture plants, and how this is related to the seasonal behaviour of the above ground parts. It entails the description of morphological root characters and development of new roots as affected by season and thus parallels the studies that are mooted for the above ground parts of pasture plants.

The particular objects of this investigation are as follows:-

1. To set down seasonal changes observed in the root systems of the plants chosen for trial, and to measure these changes where possible.
2. To relate the different root changes in combination, to seasonal variation in production and persistency of growth of the pasture plants studied.

How useful work of this nature is likely to be to the plant breeder is a matter of pure conjecture, but it is apparent that, combined with the results of similar studies of the seasonal influences on top growth, a more adequate picture of the growth of pasture plants would be obtained.

The literature bearing on the seasonal aspects of root growth in pasture plants is not extensive. Investigations made on root systems have been more of the nature of enquiries into the effects of environmental factors such as moisture, temperature, light, aeration of the soil, soil fertility and different types of management of these plants on root development and growth. Prior to the work of Sprague (1933), seasonal growth studies on roots over a year or more had been made principally on fruit and forest trees by McDougall (1916), Harris (1926) and Collison (1935). It can be seen that the important details of seasonal root growth - development and changes in terms of extent, both lateral and vertical, weight, deterioration, and new rooting with the time of year have only recently received attention from botanists and agriculturists.

Early conceptions of the seasonal growth of pasture plants were probably founded on the ideas held by horticulturists. According to Goff (1898) it was common to find stated in horticultural publications, that fibrous roots of perennial plants die in the autumn and are renewed on resumption of growth in the spring. Goff indicates that this view was commonly held in reference to perennial pasture species. In the same paper (1898), he describes his investigations in which he found that root replacement did not occur in many species of forest trees, fruit trees and shrubs, but on the contrary, new growth of the fibrous roots generally began from the identical tips where it ceased in the autumn, the time, and development in terms of length, varying with the species. It was also found by the same author that the roots of *Rubus* species and *Agropyron repens* appear to make considerable growth before any visible growth of the plants above ground in the spring. The value of this work does not lie so much in its direct application to economic pasture plants, but rather in its early contribution to the appreciation of the fact that there is great variation in seasonal root behaviour among plant species.

The first direct investigation of the seasonal root growth of pasture plants was made by Sprague (1933) on two species of

cultivated grasses, Kentucky bluegrass (*Poa pratensis*) and Colonial bent (*Agrostis vulgaris*). Two important findings were :

- (i) in the spring, bluegrass formed new roots approximately two weeks earlier than bent grass.
- (ii) maximum root weight for bluegrass occurred in early May and practically two weeks later for bent grass. The maximum root weight was approximately twice as great as at the beginning of the season, indicating that at least one half of the root system is newly generated by each spring.

Sprague ascribes the difference between species in the formation of new roots to a difference in the minimum temperatures at which growth can proceed.

The length of life of roots in five species of range grasses was studied by Stoddart (1935), who states that hitherto, no study of this nature had been made. Using the banding technique suggested by Weaver (1932), and subjecting the plants grown to all degrees of soil moisture from below wilting coefficient to saturation point, and to temperatures from 0°F to 112°F, he came to the conclusion that roots of these species live for at least one year and many in excess of two. Here again, variation between species was found, this time in length of life of roots.

The roots of ten cultivated pasture species were placed in two classes, "Annual" and "Perennial" by Stuckey (1941), the former being those which the writer found to regenerate each year, the later being those in which maximum production of roots occurred during the first year and remained functional for more than one year. The following table is Stuckey's classification of the species studied :

"ANNUAL"	"PERENNIAL"
Timothy	Kentucky Bluegrass
Red Top	Canada Bluegrass
Meadow Fescue	Orchard Grass
Rough-stalked Meadow Grass	Crested Wheat Grass
Perennial Ryegrass	
Colonial Bent (probably)	

Most new root growth began in the autumn, continuing into the winter, ceasing during the coldest month (January), and resuming in early spring as the temperatures rose, maximum increase in the number of new roots

being in the spring after the thaw for most species. Growth ceased in the summer, coinciding with periods of high soil temperatures. There was some considerable variation between species as regards time of onset and cessation of root growth.

According to Stuckey, new root growth in the "annual" type of root is followed by disintegration of the old roots as soon as the former have become established, while in the "perennial" type only a small percentage of the old roots disintegrate and only a few new roots develop.

The length of life of the roots of ten species of perennial range and pasture grasses was studied by Weaver and Zink (1946). All these grasses showed a high rate of root survival in the first year. No losses or replacements of root systems were reported, so that the results were in agreement with those obtained by Stoddart (1935), who also worked with prairie species. From these investigations it appears that there is a sharp difference between the seasonal root behaviour of the native prairie species of the United States and the European or cultivated species. The latter demonstrate annual replacement of roots by new growth, varying with species in quantity and time of growth, while the former have root systems which are more permanent in nature.

There seems to have been no work done directly on the seasonal growth of grass roots apart from that summarised above. Pavlychenko (1942) mentions that root development of Agropyron cristatum, Agropyron pauciflorum and Bromus inermis was greatly retarded or ceased entirely 180 days during the autumn, winter and spring, between the first and second seasons of growth, but pursues the subject no further.

It will be observed that no literature concerning the seasonal root growth of clovers has been cited. The only reference that could be found on the subject is that of Erith (1924) in connection with her work on white clover. She makes several pertinent statements regarding the development of the adventitious root system. Plants grown from seed sown in April and examined in July possessed few adventitious roots, but on the stolons of the same plants in September (late summer) there were numerous roots. In wild clover plants one

adventitious root is produced at each node of the stolon, and occasionally two roots appear at the same node. These roots often grow to considerable length (4-6 inches) before forming lateral branches. Erith states also, that later, the adventitious root system from each node resembles a typical tap root system. She does not mention the behaviour or the fate of the primary root system.

The deficiencies in present knowledge of seasonal root growth are obvious. The differences between species alone offers wide scope for detailed study, and while the time of the onset and new root growth in some species of grasses has been recorded, there is a paucity of data on root deterioration and its nature. Jacques (1941) in reference to perennial ryegrass states: "... there is deterioration in the cortex and the absorbing surface of the more superficial or older portions of the roots before the dry weather sets in..." The relationship between seasonal growth of roots (including new growth and deterioration, increase in length, spread, branching, etc.) and leaf growth or 'production' has not been determined, although some work has been done on the effect of environmental factors on the root-shoot ratio of trees and some grasses without reference to changes in these factors due to season, e.g. Austin (1923) - influence of pruning, Weaver and Himmel (1929) - effect of illumination, etc. However, the knowledge gained from botanical studies on the effects of environmental factors and agricultural studies on the effects of different forms of management on root growth, will aid greatly in the interpretation and understanding of the various phenomena associated with the seasonal behaviour of roots.

SECTION III.PLAN: OF INVESTIGATION.(i) Materials.

It was decided that the investigation would be conducted on the following ten pasture plants cultivated in New Zealand:

<u>Clovers.</u>	Trifolium pratense	(a) Montgomery red clover. (b) Broad red clover.
	Trifolium repens	(a) No.1 N.Z. white clover. (b) A poor strain of white clover.
<u>Grasses.</u>	Dactylis glomerata	(a) G23 cocksfoot. (b) A Danish type cocksfoot.
	Lolium westerwoldicum	- Western Wolths ryegrass.
	Lolium multiflorum	- Italian ryegrass.
	Lolium perenne	- Perennial ryegrass

Short rotation ryegrass - a selection from a cross of L.perenne and L.multiflorum produced by the Plant Research Bureau, N.Z.

The contrast of types in both clovers and grasses is fairly wide. In the red clovers, the broad red may be considered a temporary type, while Montgomery red is more persistent; in the white clovers, the range is extreme from a poor strain to the best type of permanent pasture white clover.

Similarly in the grasses, both short lived and persistent types are included. The former are represented in the ryegrasses by Western Wolths and Italian, the latter by perennial ryegrass, while the short rotation ryegrass can be regarded as intermediate between the two. The status of Danish cocksfoot in New Zealand is not determined by any production figures from the Plant Research Bureau, but can be arbitrarily classified as fairly persistent if subjected to management favourable to its survival, but less persistent than the New Zealand G23 strain.

Because uniformity within each species could be virtually assured, it was thought advisable to plant single tillers of one plant of each species rather than use seed to obtain plants for examination. While no objections could be raised towards adopting this method in the grasses, the clovers presented a problem in that, by taking clones, tap-root formation might not be similar to that when the plants are propagated by seed. Weaver (1926) states, "In the case of certain clovers which propagate by runners, the roots of the new plants arising from these are entirely adventitious." The white clovers fall into this

Figure 1. Diagram of randomisation of plots for planting and lifting.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	PW 5	It 10	H1 3	C23 9	IW 3	PCx 6	BR 14	MR 9	Per 7	WW 13	MR 5	H1 9	BR 10	It 9	Per 5	WW 10	PW 1	C23 14	PCx 13	IW 4
B	H1 12	MR 8	C23 1	It 7	PW 14	Per 1	1W 1	PCx 10	WW 3	BR 11	BR 1	PCx 11	Per 4	WW 11	C23 12	IW 5	PW 10	It 3	MR 13	H1 1
C	H1 7	PCx 12	BR 3	MR 4	Per 3	WW 12	It 13	1W 6	C23 4	PW 12	PCx 7	PW 8	It 11	Per 14	H1 8	IW 13	C23 11	BR 7	WW 4	MR 6
D	WW 6	It 2	BR 13	IW 10	C23 2	PCx 1	H1 13	Per 9	PW 4	MR 12	IW 11	BR 2	Per 2	MR 1	H1 2	It 8	WW 2	PW 9	PCx 4	C23 8
E	BR 6	MR 10	WW 9	C23 5	PW 13	It 4	Per 8	H1 10	PCx 7	IW 8	Per 13	WW 1	PW 7	BR 12	C23 6	H1 11	IW 12	PCx 5	It 5	MR 7
F	BR 4	PCx 9	WW 5	It 12	PW 2	MR 3	C23 13	H1 4	Per 11	IW 9	C23 3	It 1	BR 5	IW 7	WW 8	H1 5	PCx 14	MR 11	Per 10	PW 3
G	H1 14	IW 14	It 6	BR 8	PW 11	C23 7	MR 14	Per 6	WW 14	PCx 3	MR 2	It 14	H1 6	PCx 2	PW 6	Per 12	WW 7	IW 2	C23 10	BR 9

Each square represents a 12" glazed pipe sunken into the ground, twelve inches from its surrounding pipes. The upper symbols in each square represent the species or strain which each pipe contains and the lower symbols indicate at which lifting the plants were examined.

KEY	Species or Strains	Time of Lifting
BR	- Broad red clover	1 - Mid-Nov. 1946
MR	- Montgomery red clover	2 - Early Dec. 1946
PW	- Poor strain of white clover	3 - Mid Jan 1947
1W	- No. 1 white clover	4 - Early Feb. 1947
PCx	- Danish Cocksfoot	5 - Late Feb. 1947
C23	- C23 N.Z. Cocksfoot	6 - Mid March 1947
WW	- Western wolths Ryegrass	7 - Early April 1947
It	- Italian Ryegrass	8 - Late April 1947
Per	- Perennial Ryegrass	9 - Mid May 1947
H1	- Short Rotation Ryegrass	10 - Early June 1947
		11 - Late June 1947
		12 - Mid July 1947
		13 - Early Aug. 1947
		14 - Late Aug. 1947

class and since there was no guarantee that the tap root would develop normally when the plant was obtained by planting runners, and also that it is difficult to obtain uniformity in the cuttings (as regards number of nodes from which roots form), it was decided to grow the plants from seed. The rooting habits of red clover being unknown, it was considered a necessary precaution to use seed also.

To avoid heterogeneity in the seed as far as possible, nucleus stock seed of Montgomery red clover (Type Aa.581) and No.1 White clover (Type 4.W13) were obtained from the Plant Research Bureau. From the same source, broad red clover (Type Aa.580) and a poor strain of white clover (Type Aa.2541) seeds were acquired.

Single plants of the two types of cocksfoot, perennial ryegrass, Italian ryegrass, and short rotation ryegrass were obtained from the control rows of increase plots at the Plant Research Bureau, and a plant of Western Wolths was also obtained from there. From these plants, tillers were obtained for planting.

(ii) The Plots - Planting and treatment.

A plot was prepared on the Massey College dairy farm in April, 1946, on a paddock that had been recently sown down to pasture. The area was 50 feet by 30 feet, being free draining, free from shade and yet shielded by hedges from strong winds. Planting was randomised (Figure 1) to minimise the effects of soil heterogeneity, and the actual planting was carried out on May 11, 1946. The plants were planted in glazed drain pipes, 12 inches in length and 12 inches in diameter. Glazed pipes were preferred since they reduce the tendency of roots to congregate around the sides, a feature that is most marked in the unglazed type, as Jacques (1941) noted. The pipes were sunk to just under ground level 12 inches apart, in rows 12 inches apart as in Fig.1. Clover plants, one month old, grown from seed in boxes were selected for uniformity and transplanted directly into the pipes, two of each type per pipe, there being 14 pipes for each type of clover. The single plants of the grasses were divided into single tillers of uniform size and planted, three of each type in a pipe, there being 14 pipes for each species or strain. What was left of the grasses and clovers was planted in the soil, not in pipes, away from the sunken pipes as a check on type. The method is that adopted by Jacques (1937, 1941) and may be termed a

modification of what Pavlychenko (1937) calls the "Soil-containers Method" of root development study.

At planting, $\frac{1}{5}$ oz. of superphosphate was added to each pipe and mixed with the top inch of soil. This represents a dressing of between three and four hundredweight of superphosphate per acre. No fertiliser was subsequently applied. The plants were cut to $1\frac{1}{2}$ - 2 inches above ground every three weeks, approximately, the object being to maintain them as nearly as possible to the condition of plants growing in the field, without, however, inducing checks to tillering as described by Roberts and Hunt (1936), or to rooting as described by Jacques (1937) by too frequent cutting of the tops. The pipes and surrounding ground were kept clear of weeds throughout the trial.

(iii) Observations.

Observations were begun on November 15, 1946, and carried on at 20 day intervals until September 1947, extending over a period of 10 months and entailing the observation of 14 pipes of each species or strain. The observations consisted of two processes:

- (a) Lifting of pipes from the soil and washing away of the soil surrounding the roots.
- (b) Examination of the plant in the laboratory.

(a) Lifting.

Since one pipe of each species or strain was required, ten pipes were lifted at each observation. Each set of observations took about five days to complete. The lifting order for each type was randomised to assure that no selection was exercised in event of any variation in top growth between pipes containing the same species. This order is shown in Fig.1.

The actual lifting procedure was as follows: Firstly the pipe was dug out of the ground, then taken clear of the occupied portion of the plot where it was immersed in water for about half an hour. This immersion made the subsequent washing-away of the soil within the pipe less tedious than direct washing after lifting. The lower end of the pipe was then sprayed with water from a $\frac{1}{2}$ " hose to remove the soil from the roots gradually. No pressure nozzle was used on the hose since

enough force could be obtained by restraining the flow of water from the mouth of the hose with the operator's finger. After washing, the plants were kept moist by enclosing them in damp calico bags suitably labelled until the lifting was complete and they could be transferred to the laboratory.

(b) Laboratory examination.

As soon as the plants were brought to the laboratory, the root system was immersed in water contained in rectangular glass jars while awaiting examination. The following table of results was made at each lifting of the clovers:

Section A. Plant examined entire.

1. Length of root system - taken from the point of attachment of the root to stems, to the tip of the longest root.
2. Condition of the cortex - Colour; nature of deterioration, if any; extent of such deterioration.
3. Visual comparison between root systems of the different clovers.
4. Number of tillers or stolons per plant.
5. Conditions of leafage.
6. General notes.

Section B. Examination of roots after separation from the remainder of the plant at the point of attachment.

1. Number of laterals of the first order.
- * 2. Extent of branching of the laterals (1st, 2nd, 3rd, etc., order).
3. Diameter of the tap root (1 inch from the point of attachment).
- * 4. Diameter of branches of the first order ($\frac{1}{8}$ " from point of attachment).
5. Root hair development on tap root
 - * laterals
 - * branches of 1st, 2nd, 3rd, etc., order.
6. Length of longest root hair found.
7. New rooting. Nature of new rooting, amount, branching, root hair development.
8. General notes.
9. Root weights - Roots air dried and weighed at constant humidity in humidity room. All weighed Sept. 2, 1947, at relative humidity of 66%.
- * Indicates those observations in which samples of 20 roots were taken at random from the root system and the average figure taken.

The following table of observations was made at each lifting of the grasses.

Section A. Plant examined entire.

1. Length of root system - taken from the point of attachment to the tip of the longest root.
2. Condition of the cortex - Colour and nature and extent of deterioration, if any.
3. Visual comparison of roots between species.
4. Number of tillers per plant.
5. Condition of foliage.
6. General notes.

Section B. Examination after the roots had been separated from the rest of the plant at the point of attachment to the tillers.

1. Number of roots.
 2. Diameter of the largest white root (1" from point of attachment).
 3. Diameter of the smallest white root (1" from point of attachment).
 - * 4. Number of laterals in the top 6 inches of root length.
 - * 5. Extent of branching (1st, 2nd, 3rd, etc., order).
 - * 6. Diameter of branches of 1st order ($\frac{1}{2}$ " from point of attachment).
 - * 7. Root hair development on main white roots and branches of 1st, 2nd, etc., order.
 8. Position of the greatest frequency of root hairs.
 9. Length of longest root hair observed.
 10. New rooting - Numbers, nature and branching, etc., of new roots.
 11. General notes.
 12. Root weight. As for clovers.
- * Indicates those observations in which samples of 20 roots were taken at random from the root system, and the average figure taken.

The nomenclature adopted in the care of grasses is that used by Jacques (1939).

Many of the measurements made were found to have no application to the subject, whilst factors such as cortex colour and condition, deterioration, new rooting, for example, were of utmost importance in considering the seasonal root growth of pasture plants. Some measurements such as length of root had to be most carefully considered as far as its effects were concerned, since in the ground, the roots extended only into the top twelve inches of soil, and the figures for this measurement were often over 20 inches, due to lateral spread and entanglement, which could not be measured since the plants were grown in restricted areas.

Some difficulty was encountered in measuring deterioration in both clovers and grasses. In the former, the tap root was found to be the main consideration. The end point of deterioration was the death of the tap root, which was manifest by its rotting away. The intermediate steps were difficult to measure objectively, so that a system of arbitrary units was set up.

- A - First signs of deterioration.
- B - Portions of roots showing deterioration - under half the length of the tap-root.
- C - Portions showing deterioration - over half of the tap-root and showing plainly on the branches.
- D - Tap-root entirely blackened.
- E - Disintegration of the tap root.

Root deterioration per plant in the grasses was measured by the number of roots affected by sloughing of the cortex, but whether the roots died or not after this was difficult to determine. Weaver and Zink (1946) assert that there is no completely satisfactory test to determine whether grass roots are dead or alive. For such determinations, the afore mentioned workers used tests of tensile strength, colour, etc., with species of which they had had much experience. The method used in this investigation was to attempt to combine Weaver and Zink's qualitative tests with a quantitative one. This latter was done by first obtaining counts of roots per tiller of each plant in the first few liftings before the plant produced new roots. Then at all subsequent observations, the number of old and new roots per tiller were taken, as well as the number of new tillers. Thus it was thought that the rate of survival, or more properly, the death of old roots through the period of the trial might be determined. However, the problem of recognising all the new tillers on different plants of the same species at different liftings made the determinations difficult and the verity of the resultant figures questionable.

SECTION IV. RESULTS.

The results of this investigation are arranged in the following order.

- A. Red Clovers: 2 types - Broad red clover and Montgomery red clover.
- B. White Clover: 2 types - A poor strain and No.1 N.Z. White clover.
- C. Cocksfoot: 2 types - A Danish strain and C.23 (N.Z. strain).
- D. The Ryegrasses: 4 species - Perennial ryegrass, Italian ryegrass,
Short Rotation ryegrass and Western Wolths.

In each of these sections, the results for the individual species or strains are set out as follows:

- (i) Amount of deterioration and new rooting through the trial.
- (ii) Discussion of the relationship of deterioration and new rooting to seasonal production of the individual species.
- (iii) Seasonal growth of new roots.
- (iv) In grasses only - The amount of survival of the old adventitious root system.
- (v) Root hair development.
- (vi) Other observations which showed little or no seasonal significance.

Some discussion is included in this section to prevent undue dispersion of data of individual species or strains and the comments derived from them. A general discussion forms the Section (V).

For representative production figures of the grasses and clovers tested, yield figures from the P.R.B. are used where it was possible to obtain them. In the case of C.23 cocksfoot, perennial ryegrass, short rotation ryegrass, pedigree white clover and a poor strain of white clover, the figures utilised represented yield trials from the P.R.B. which extended over the same period as these root investigations; but in Italian ryegrass and both red clovers the seasonal yield figures were not of the same period. The seed used in these P.R.B. trials were of the same lines as those from which the plants used in this investigation originated. No figures were obtainable on seasonal yields of Western Wolths or Danish cocksfoot.

From the figures available, production graphs, representing seasonal leaf growth were derived for the purpose of comparison with seasonal root behaviour.



Figure 2. Portion of a tiller of Montgomery red clover showing adventitious rooting from the nodes.

(Photograph taken 13th May, 1947.)

A. THE RED CLOVERS.

The initial observations were made on the two strains of red clover on November 15, 1946, when the plants had been growing in the pots for 188 days. The roots of the plants lifted were grey-white in colour, the tap roots and thick laterals being lighter in colour than the branches and smaller roots. Root hair development was fairly extensive, especially on the branches, but was totally lacking on the tap roots. This condition prevailed throughout the period of the trial. No new rooting was recognised in the plants lifted until the third lifting (Jan.16, 1947) in the case of Montgomery red clover, and the fifth lifting (Feb.24, 1947) in the case of Broad red clover. New root growth recognised was classified into two types according to the position from which it originated.

1. Crown roots - Tangled, relatively short roots which grew from the tap root about 1" from the point of attachment of the latter to the above-ground parts.
2. Adventitious tiller rooting - Formed on the stems (Fig.2) mainly within a radius of 6" from the centre of the plant, at the nodes. Mostly there was one root per node, sometimes two and as many as four were observed.

These new roots were readily distinguishable from the old roots by their comparative size, softness, and shiny appearance.

The adventitious tiller rooting was measured as number of roots per tiller, but owing to the difficulty in accurate counting of the entangled fine crown roots, these were estimated merely as a number per plant.

Deterioration was initially observed at the same time in the two individual strains as new rooting. First signs consisted of darkening of the primary root system, then the appearance of dark patches in the region of the tap root near to the crown of the plant (Fig.3). As with subsequent liftings an intensification of this condition was observed until a stage was reached where the tap root became detached by a rotting process from the rest of the plant about 1 - 2" from its point of attachment (Fig.4). Some of the laterals above this rotting point remained, and deterioration in the form of black patches forming was noted (Fig.3.).



Figure 3. Root system of broad red clover, arrow indicating first signs of deterioration (A) of the primary root system.

(Photograph taken 24th February, 1947.)



Figure 4. Root system of broad red clover (branches removed), showing advanced stage of deterioration (E).

- a - Former position of tap-root.
- b - Dark patches on laterals - beginning of deterioration.

(Photograph taken 13th July, 1947.)

Deterioration was measured as indicated in Section III.

Broad Red Clover.

(1) Deterioration and New Growth of Roots.

The degree of deterioration and the new rooting in broad red clover are shown in table I.

Table I - Deterioration of the Primary Root System and New Growth of Roots in Broad Red Clover.

Lifting No.	Date	No. Plants per Lifting.	Colour of Primary Root System.	Deterioration of Primary Root System.	New Rooting	
					No. Crown roots/Plant.	No. Adventitious roots/tiller.
1	15/11/46	2	Grey-white	-	-	-
2	5/12/46	2	"	-	-	-
3	16/1/47	1	Straw colour	-	-	-
4	3/2/47	2	Darkening	-	-	-
5	24/2/47	2	Patches evident.	A A	Very few	Very few
6	14/3/47	1	Light brown. Increase in black area.	B	35	3
7	4/4/47	2	" "	B C	90	5
8	25/4/47	2	" "	B B	95	12
9	13/5/47	2	Lighter than previous.	A A	130	10
10	4/6/47	2	Light brown.	B B	150	13
11	24/6/47	1	Most blackened.	D	80	14
12	13/7/47	1	Tap root disintegrated.	E	40	14
13	4/8/47	2	Blackened	C D	55	16
14	30/8/47	2	"	D E	35	18

From column 5 (Table I), it will be noted that there is not the progressive intensification of deterioration from February onwards which might be expected, were the observations able to be made on a single plant or on different plants of the same hereditary nature grown under similar conditions. There was lack of uniformity of behaviour even in plants grown in the same pipe as shown in liftings



Figure 5a. Leaf production and primary root deterioration in Broad red clover.
 — leaf production: — deterioration.

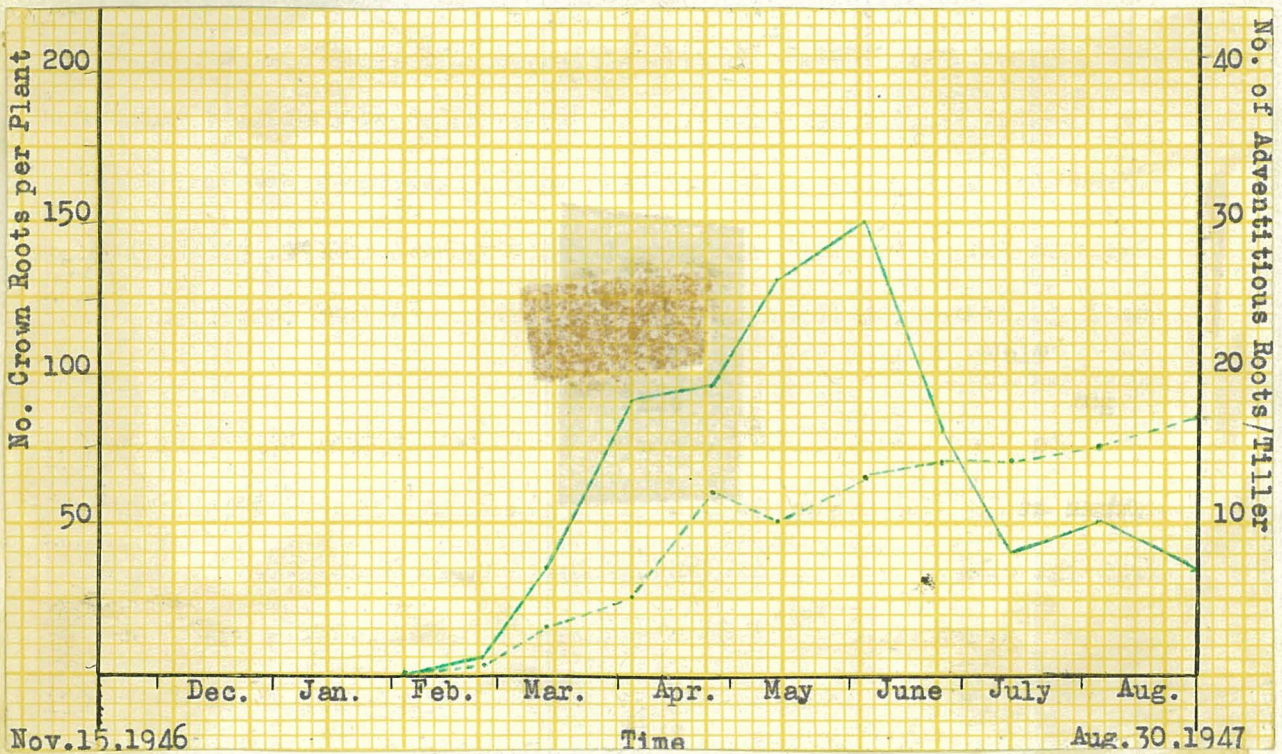


Figure 5b. New rooting in broad red clover.
 — crown roots: - - - - - adventitious roots.

7, 13, 14. This serves to emphasise the genetic variability in any line of seed. On this data, the most that can be said is that there is a trend for increase in deterioration of the primary root system until winter when it reaches a climax, i.e. disintegration. Figures 3 and 4 illustrate the beginning and end point of this tendency. The number of adventitious roots per tiller showed a more or less progressive increase through the trial, but the number of crown roots per plant decreased when the primary root system was at an advanced stage of deterioration (Fig.5, a & b). This was probably due to their rotting away with the portion of the tap root to which they were attached.

(ii) The relationship of deterioration of the primary root system and new root growth to seasonal production in Broad red clover.

Figures 5a and 5b compare graphically the seasonal growth of the foliage of broad red clover in terms of dry matter per acre production with the two main seasonal changes in roots - deterioration and new growth. The curves for the latter are derived from Table I, while the production line is derived from data of yield trials conducted by the P.R.B. 1946-47. These figures were not taken at regular intervals, but according to the amount of growth. Thus for example in the period between May and September, 1946, (104 days), only one cut was taken. For comparisons, adjustments were made to the figures by finding the daily production per acre at each cut and adjusting the figures to 20 day intervals to approach the periods of observations of the root systems. The original source, derivation and figures used in the construction of this line are shown in Appendix I.

In figure 5a, it can be seen that deterioration begins in the autumn at the time when there is some check in the fall in production from the summer months. Owing to the nature of the plants used in the root trial, the deterioration curve is inconsistent, but there appears to be a tendency for intensified deterioration as production falls over the winter.

In figure 5b, the two classes of new rooting are graphed. Both begin in February at the same time as deterioration. Crown rooting shows an increase with the fall in production (Fig.5a) until June

when there is a decrease in number, as previously noted. The new adventitious rooting however, shows a fairly uniform increase with fall in production.

(iii) The seasonal growth of the new adventitious roots.

Table II shows measurements taken of some of the components of growth in the new adventitious roots, the first of which were observed in February, 1947. The plants, till that stage, apparently existed on the action of the primary root system alone in the soil.

Table II. Seasonal Growth of the new adventitious roots.

Lifting No.	Date	Length of Longest Root observed.	Extent of Branching.	Diameter of Longest root observed.
5	24/2/47	$\frac{1}{4}$ "	-	.5 m.m.
6	14/3/47	1"	1st order	.7 m.m.
7	4/4/47	3"	1st "	1.2 m.m.
8	25/4/47	4"	2nd "	1.2 m.m.
9	13/5/47	4"	2nd "	1.3 m.m.
10	4/6/47	7"	2nd "	1.9 m.m.
11	24/6/47	5"	2nd "	1.5 m.m.
12	13/7/47	9"	3rd "	1.8 m.m.
13	4/8/47	11"	3rd "	2.2 m.m.
14	30/8/47	8"	3rd "	2.3 m.m.

(iv) Root Hair Development.

No satisfactory method of measuring root hair development was arrived at, but some facts were noted. In the primary root system in the first observations, before the onset of deterioration, the tap root and laterals from it were lacking in root hair development, and remained so throughout the trial. Development was fairly profuse on the branches of the laterals, especially on those of the second order. In the May observation the root hair seemed to decrease till in the last observation August, there were comparatively few, although the branches of the second order still showed the greater concentration.

(v) Other observations.

Grouped in Table III are those observations to which little significance could be attached in relation to seasonal growth. While it was not expected that the length of the root system would be of value since only the top 12 inches of soil were taken at each observations, it was thought that tap root diameter and number of tillers would show some significance. From the figures obtained using this technique, this was obviously not the case.

Table III. Measurements of the Primary Root System in Broad Red Clover.

Lifting No.	Length of Root system.	Tap root Diameter 1" from attachment. m.m's.	No. of laterals from tap root.	Extent of Branching in Primary root system.	Weight of Primary root system. 2 plants. gms.	No. Tillers
1 Nov.	24"	5.5, 6.0	20 17	3rd order.	34	17 19
2 1946	19"	8.7, 5.4	18 21	3rd "	32	23 16
3	22"	6.3	19	3rd "	* 16.1	28
4	21"	11.1, 4.9	17 21	4th "	21.5	14 15
5	20"	9.5, 8.8	21 21	4th "	* 14.4	25 13
6	17"	9.0	25	4th "	32.6	39
7	21"	9.5, 8.6	24 17	4th "	42.8	48 17
8	22"	12.4, 10.2	16 18	4th "	41.9	22 35
9	20"	10.2, 10.8	17 14	4th "	42.4	27 20
10	20"	12.0, 7.9	10 13	4th "	62.0	45 12
11	18"	11.7	8	4th "	* 30.9	21
12	19"	-	4	3rd "	* 31.8	22
13 Aug.	21"	12.5, 11.3	16 10	4th "	50.6	32 18
14 1947	20"	9.6, 10.6	9 6	4th "	-	19 22

* Indicates weight of one plant only.

The only measurements of any significance is that of the number of laterals from the tap root, which shows a decrease in winter, complementary with the deterioration of the tap root and the consequent detachment of laterals with it.

Montgomery Red Clover.

(i) Deterioration and New Growth of Roots.

The nature of deterioration of the main root system and new growth of roots of Montgomery red clover is similar to that of broad red clover. As Table IV illustrates, there is variation in the time of onset of deterioration being first observed in Montgomery red clover about two months before that in broad red. It will be noticed that at no stage is the tap root observed to become detached from the plant. Thus it appears that although deterioration begins in the primary root system earlier in Montgomery red clover than in broad red, its tap root is more persistent. As was the case in broad red clover, there was variation in extent of deterioration both in successive liftings and in the plants occupying the same pipe.

The seasonal trends of new rootings of Montgomery red clover are also similar to broad red clover in respect to both crown and adventitious tiller roots. New rooting was observed at the fifth lifting (February 24th, 1947).

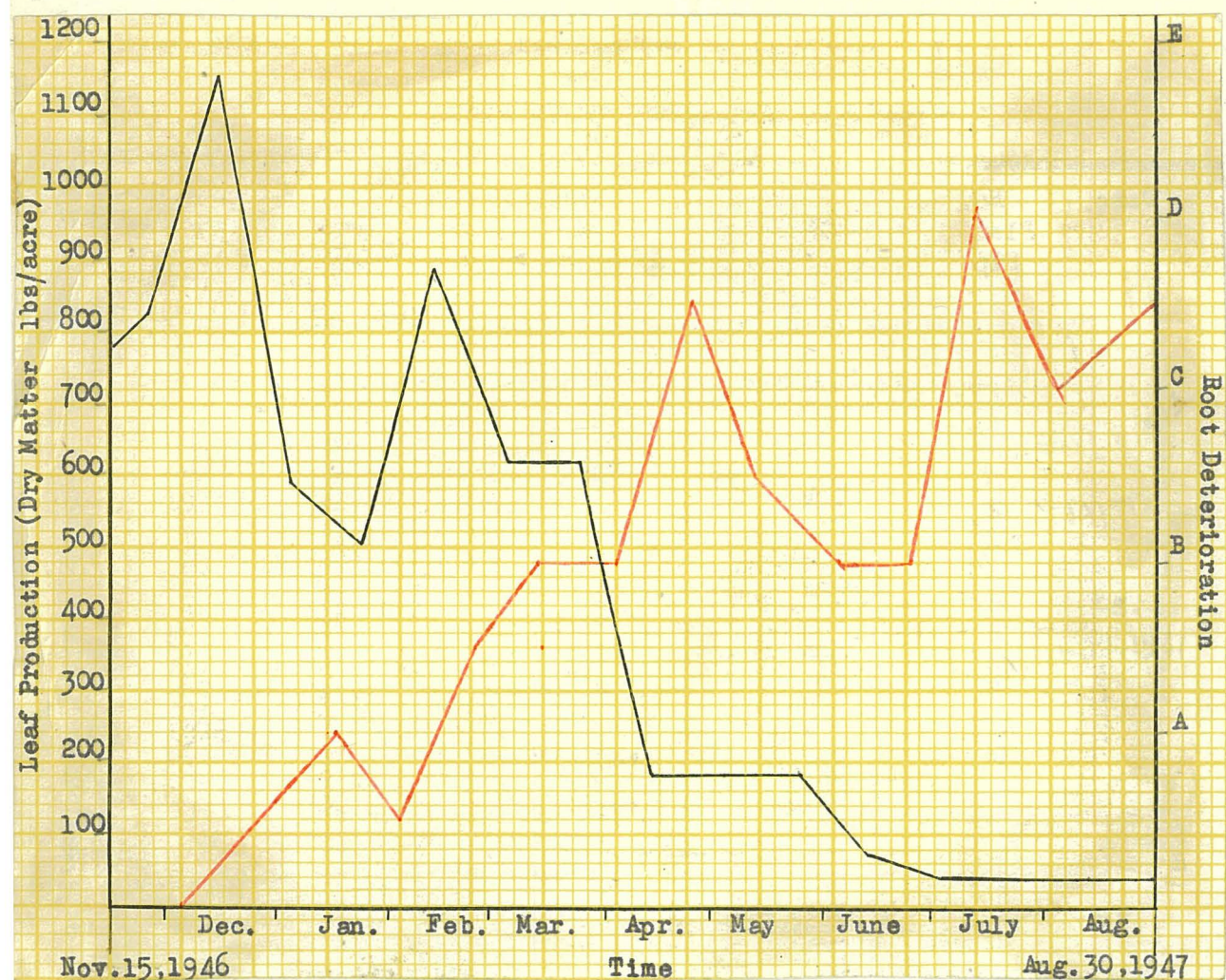


Figure 6a. Leaf production and primary root deterioration in Montgomery red clover.
 — leaf production: — deterioration.

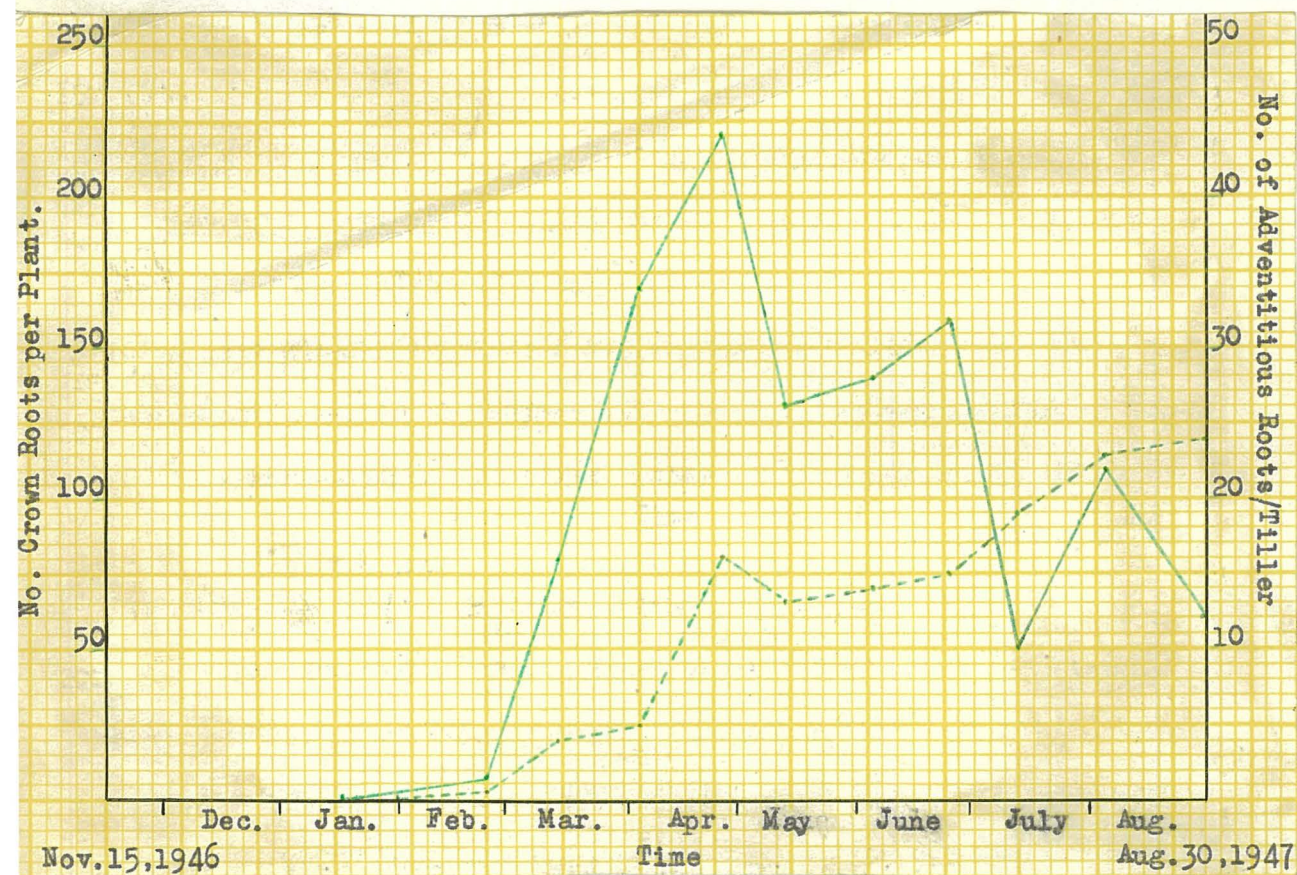


Figure 6b. New rooting in Montgomery red clover.
 — crown roots: - - - - - adventitious roots.

Table IV. Deterioration of the Primary Root System and New Root Growth in Montgomery Red Clover.

Lifting No.	Date	No. Plants/Pipe.	Colour of Primary Root System.	Deterioration of Primary Root System.		New Rooting	
						No. Crown roots/Plant.	No. Adventitious roots/Tiller.
1	15/11/46	2	White	-	-	-	-
2	5/12/46	2	"	-	-	-	-
3	16/1/47	2	Light Straw	A	A	-	-
4	3/2/47	2	"	-	A	-	-
5	24/2/47	2	Darkening	A	B	7	$\frac{1}{2}$
6	14/3/47	2	Dark Patches	B	B	80	4
7	4/4/47	2	"	B	B	170	5
8	25/4/47	2	Intensification	C	D	220	16
9	13/5/47	2	Light Brown	B	C	130	13
10	4/6/47	2	"	B	B	140	14
11	24/6/47	2	"	B	B	160	15
12	13/7/47	2	Black	D	D	50	19
13	4/8/47	2	Brown	C	C	120	23
14	30/8/47	2	Black	C	D	60	24

In both types of rooting, numbers were greater than in broad red clover at each lifting. As the tap root deteriorated, so the number of crown roots diminished, except for lifting 8, when the maximum number of crown roots observed during the trial could not be explained. The number of adventitious roots per tiller show a progressive increase with successive liftings except for lifting 9, when the plants observed appeared to be abnormal in all respects.

(ii) The relationship of deterioration of the primary root system and new root growth to seasonal production in Montgomery red clover.

Figures 6a and 6b illustrate the relationships between seasonal production of Montgomery red clover and primary root deterioration and new growth of roots. The source of the leaf production line is indicated in Appendix II, being derived in similar manner to that of broad red clover.

As figure 6a indicates, deterioration of the primary root system begins at the same time approximately as there is an appreciable drop in production. There appears to be a tendency for intensification of deterioration subsequently, especially after the autumn period of growth, but as in broad red clover, there is no consistency about the curve. The deterioration process appears to be much slower in Montgomery red clover.

Crown rooting increases rapidly with the fall in production in March and April, but decreases, complementary to the intensification of deterioration. Adventitious rooting begins in February and shows a steady increase throughout the remaining period of the trial as leaf production drops in the winter. Fig. 6b illustrates this.

(iii) Seasonal growth of the adventitious roots.

The seasonal growth of the adventitious roots as measured by length, diameter and extent of branching was similar to that observed in broad red clover (Table II). The diameter of the largest root observed in each observation were consistently smaller than those corresponding measurements in broad red clover. This rather conforms with the proportions of the primary root systems of the two types of red clovers. The tap roots of broad red clover were mainly greater in diameter than those of Montgomery red (Tables III and VI.)

TABLE V. Seasonal growth of the adventitious roots of Montgomery red clover.

Lifting No.	Date	Length of Longest Root observed.	Extent of Branching.	Diameter of Longest root observed.
5	24/2/47	$\frac{1}{4}$ "	-	.4 mm
6	14/3/47	$1\frac{1}{4}$ "	1st order	.6 mm
7	4/4/47	3"	2nd order	.8 mm
8	25/4/47	4"	2nd order	1.3 mm
9	13/5/47	4"	2nd order	1.0 mm
10	4/6/47	5"	2nd order	1.3 mm
11	24/6/47	12"	3rd order	1.6 mm
12	13/7/47	8"	3rd order	1.2 mm
13	4/8/47	10"	3rd order	1.9 mm
14	30/8/47	10"	3rd order	2.0 mm

(iv) Root Hair Development.

Root hair development, as far as could be observed was similar to that in Broad red clover. From observations made it seemed that root hair concentration began decreasing in late February, when deterioration of the primary root system was obvious.

On the adventitious roots that appeared in February, 1947, root hair development was strong especially near the tips. As branching became more extensive there appeared to be a decrease in the number on the main new roots and an increase in the branches, being concentrated on the 1st and 2nd order branches.

(v) Other observations.

Table VI presents data to which no significance could be attached.

TABLE VI. Measurements of Primary root system in Montgomery Red Clover.

Lifting No.	Length of primary root system.	Tap root Diameters.		No. of Laterals from Tap root.		Extent of branching in Primary root system.	Weight of Primary root system. 2 plants.	No. of tillers
		mm's						
1 Nov.'46	22"	7.3	8.0	19	17	3rd	23.3	19 27
2	22"	8.2	8.4	15	15	4th	27.0	21 20
3	24"	8.2	11.0	13	8	"	21.0	22 44
4	21"	7.6	7.8	24	11	"	22.9	24 16
5	19"	9.0	8.4	20	17	"	19.3	23 21
6	19"	8.1	9.5	22	14	"	21.9	30 33
7	19"	9.6	9.4	26	16	5th	48.3	31 48
8	18"	12.2	11.6	33	6	4th	20.8	25 22
9	19"	8.0	11.1	13	14	"	48.7	16 24
10	20"	10.1	8.2	7	10	"	51.5	35 12
11	20"	11.3	7.9	23	15	"	51.4	16 29
12	17"	6.6	9.4	14	10	"	37.8	10 34
13	19"	8.5	9.6	9	22	"	56.8	23 20
14 Aug'47	19"					"		26 17

The laterals from the tap root do not show the decrease in number that is noted in broad red clover. This corresponds to the greater degree of deterioration that is found in the latter strain.

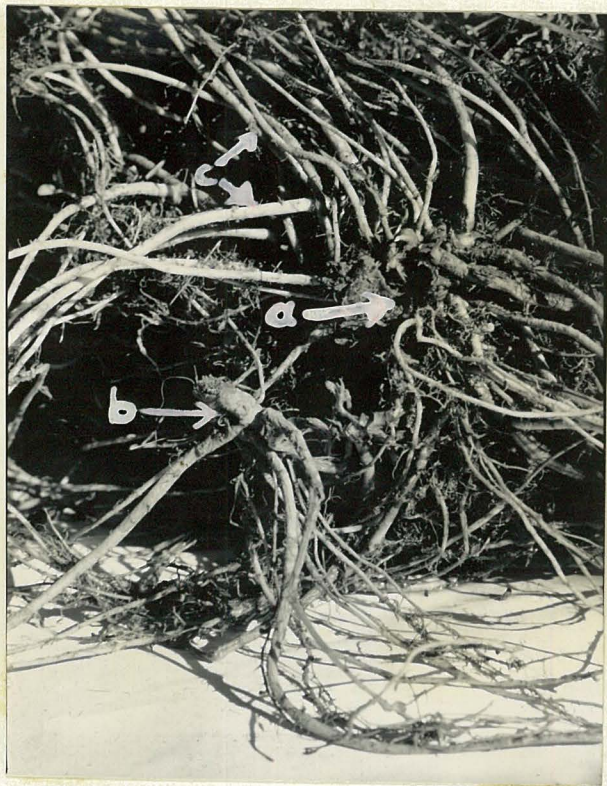


Figure 7. Plant of No.1 N.Z. white clover inverted to show complete deterioration (E) of the primary root system.

- a - Former position of primary root system.
- b - Primary root system which has become detached from the plant.
- c - Thick adventitious roots.

(Photograph taken 24th June, 1947).

B. THE WHITE CLOVERS:

The nature of seasonal growth of the roots of both strains of white clover, the ordinary N.Z. and No.1 Pedigree N.Z., was observed to be similar to that of the red clovers. Deterioration of the primary root system and new growth, both crown roots and adventitious rooting from nodes of the stolons, were observed. Root hair development was similar to that in red clovers also but at all stages prior to primary root disintegration, there seemed to be greater concentration of root hairs. The differences between seasonal root changes in white and red clovers were mainly the time of deterioration and onset of new growth, and also the extent of these two qualities. The feature in this connection which was most marked, was the dying off of the primary root system. Whereas in red clovers, the tap root rots away about 1" to 2" from the point of attachment to the above ground parts, leaving some of the laterals attached to the remaining tap root, in white clovers there is a complete dying off, the rotting affecting even the stolons to some extent, no laterals of the tap root remaining (fig.7). It is probable that this stage may be reached in the red clovers but the trial did not extend over a period long enough to corroborate this possibility.

New root growth shows similar tendencies to that in the red clovers (fig.8). Crown roots diminish in numbers with advanced deterioration of the primary root system, but the adventitious type show a steady increase.

All measurements were made on the same bases as those on the red clovers.

WHITE CLOVER. (Poor Strain).

(1) Deterioration of Primary Root System and New Root Growth.

Table VII shows the deterioration of the primary root system and the numbers of new roots observed throughout the trial.

At the first observation, November 15th, 1946, the primary root system showed no signs of deterioration, being white in colour, but some new crown and adventitious roots were noted in one of the

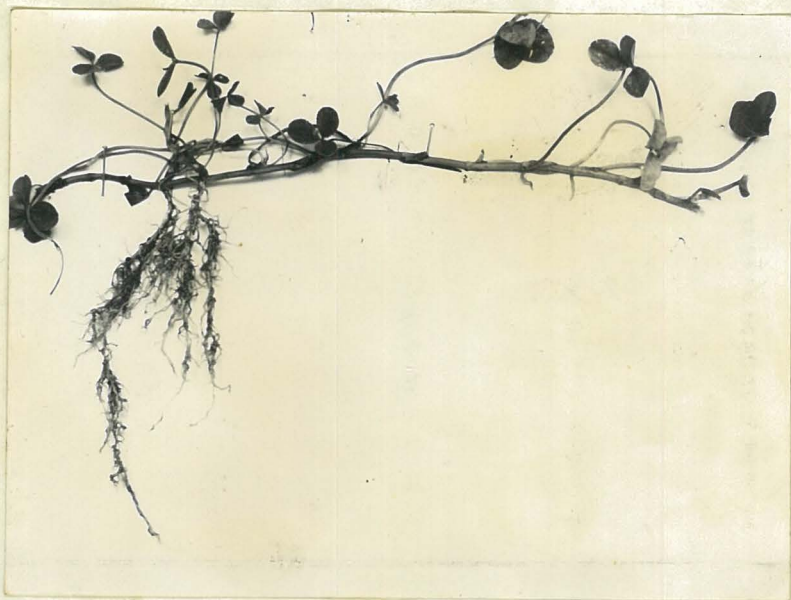


Figure 8. Portion of a stolon of poor white clover showing adventitious rooting from the nodes.

(Photograph taken 5th April, 1947).

two plants lifted.

Table VIII. Deterioration of the Primary Root System and New root growth in a poor strain of white clover.

Lifting No.	Date	No. Plants/ Pipe.	Colour of Primary Root System.	Deterioration		New Rooting	
						No. crown roots/ plant.	No. Advent- itious roots/ stolon.
1	15/11/46	2	White	-	-	11	4
2	6/12/46	2	"	-	-	8	7
3	17/1/47	2	Darkening	A	-	17	7
4	4/2/47	2	Grey	B	B	44	12
5	25/2/47	2	"	B	D	97	16
6	15/3/47	1	"	B		104	24
7	5/4/47	1	Black	D		73	37
8	28/4/47	1	-	E		51	67.
9	14/5/47	2	-	E	E	21	49
10	4/6/47	2	-	E	E	-	35
11	24/6/47	2	-	E	E	-	52
12	13/7/47	1	-	E		-	20
13	4/8/47	1	-	E		-	32
14	30/8/47	2	-	E	E	-	42

After January, 1947, deterioration intensified until the end of April, from whence all primary root systems of the plants observed had deteriorated completely. Some crown roots remained in lifting 8 and 9 when the condition E had been reached. This was due to the fact that the tap roots had not entirely rotted, some $\frac{1}{2}$ " - 1" still remained on which the crown roots were attached.

(ii) The relationship of deterioration of the primary root system and new root growth to seasonal production in ordinary N.Z. white clover.

The graphs which comprise figures 9a and 9b present comparisons of seasonal production of the poor strain of N.Z. white clover with deterioration and new growth of roots. The production line gives a better comparison than those presented in the red clover section, since it is derived from data from P.R.B. trials of the same strain used in this trial over the same period. The derivation of this line is shown in Appendix III. Both deterioration of the primary root system and the number of new roots show the same relationship to seasonal production or leaf growth as in the red clovers. It will be noted that the line representing adventitious rooting is very irregular. No explanation other than variation in the seed used to obtain the plants or the possibility

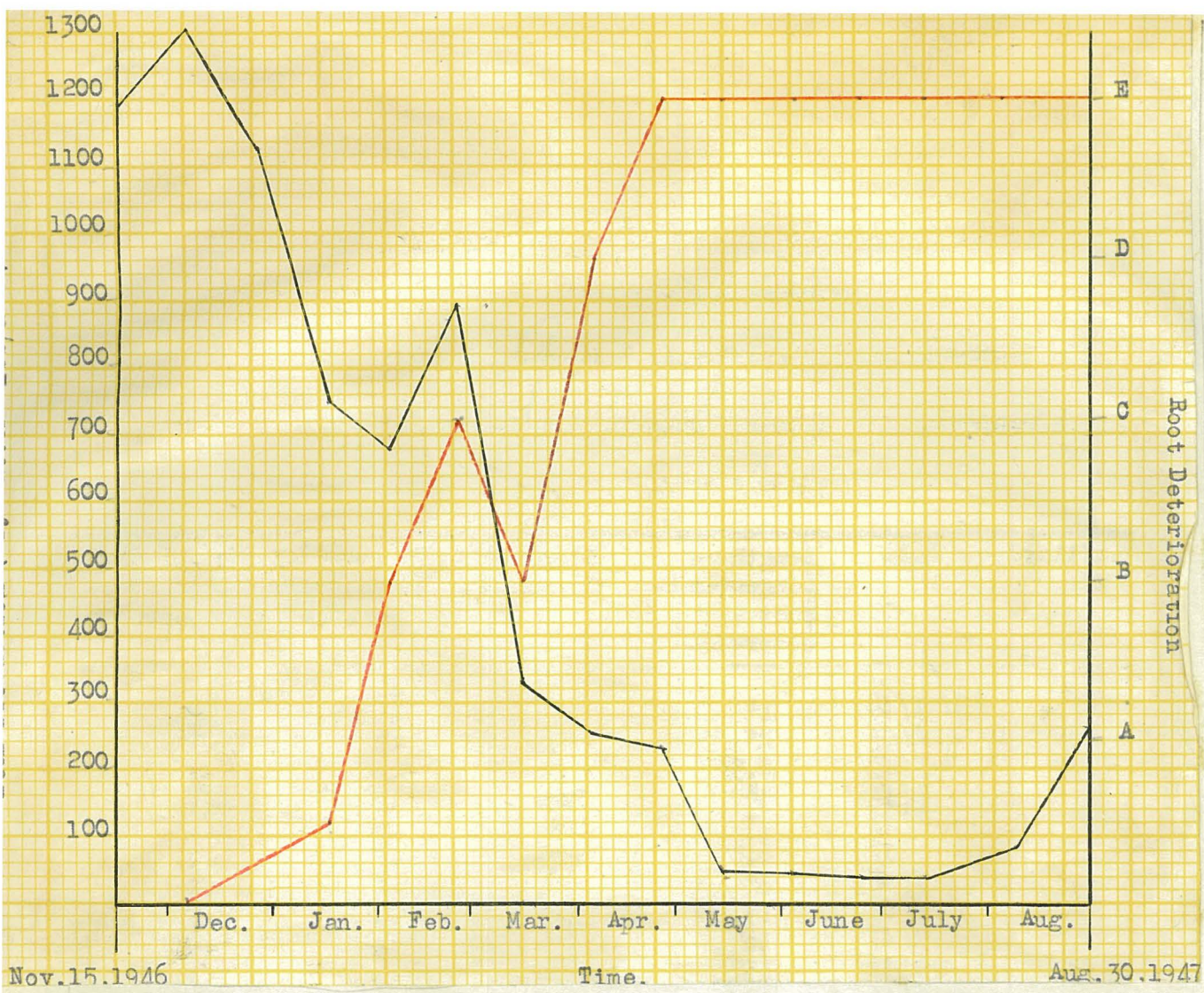


Figure 9a. Leaf production and primary root deterioration in ordinary N.Z. white clover.
 — leaf production: — deterioration.



Figure 9b. New rooting in ordinary N.Z. white clover.
 — crown roots: - - - - - adventitious roots.

of personal error in counting can be offered.

(iii) The seasonal growth of new adventitious roots.

Measurements of the adventitious roots showing some seasonal trend are presented in Table VIII.

TABLE VIII. Seasonal growth of adventitious roots of Ordinary N.Z. white clover.

Lifting No.	Date	Length of Longest new root observed.	Extent of Branching.	Diameter of largest new root.	Weight of new roots. 2 plants.
1	15/11/46	1"	-	.4 m.m	-
2	6/12/47	2"	-	.7 "	1.6 gms
3	17/1/47	2.5"	1st order	1.1 "	2.8 "
4	4/2/47	3"	2nd	1.7 "	3.5 "
5	25/2/47	7"	2nd	2.6 "	5.1 "
6	15/3/47	6.5"	2nd	1.8 "	*6.8 "
7	5/4/47	8"	3rd	3.1 "	*4.7 "
8	28/4/47	13.5"	"	2.4 "	*5.2 "
9	14/5/47	16"	"	3.1 "	6.4 "
10	4/6/47	15"	"	2.6 "	8.3 "
11	24/6/47	17.5"	"	2.8 "	12.4 "
12	13/7/47	13"	"	1.9 "	*4.8 "
13	4/8/47	14"	"	2.7 "	*6.6 "
14	30/8/47	14"	"		

* Weight of roots from 1 plant only.

Between liftings 5 and 13, there appears little tendency for change in diameter, but both weights and length do show some increase with age.

(iv) Root hair development.

Root hair concentration was greatest on the branches of the primary root system, and appeared to diminish in the observations made from February onwards. Root hair development on the adventitious roots was somewhat similar to that described in Montgomery red clover. There appeared to be greater concentration of root hairs especially at the tips of the branches than in red clover.

(v) Other observations.

Table IX presents data to which little significance could be attached. The measurements of tap-root diameter and weight of the primary root system rather substantiate the deterioration data (Table 7), in that they both show a decrease with the intensification of primary root deterioration. Since, in the case of weights in red clovers, this

relationship was not established (Tables 3 and 6), it is difficult to place much cognizance on it.

TABLE IX. Observations: Primary root system in ordinary N.Z. white clover

Lifting No.	Length of Primary root system.	Tap root Diameter.		No. laterals from tap root.		Branching Extent of Branching.	Weight of Primary root system. gms.	No. Stolons.
		m.m's						
1 Nov.' 46	19"	3.6	2.9	28	7	4th	* 8.4	26 24
2	19"	3.8	3.7	16	9	"	7.1	20 16
3	18"	4.0	3.5	11	8	"	9.4	32 26
4	21"	4.0	4.0	12	18	"	6.5	19 19
5	15"	5.0	3.4	12	13	3rd	2.0	34 27
6	16"	3.5		9	14	"	1.9	17 23
7	19"	3.8		10	11	2nd	* 2.2	16 18
8	-	-		-		-	-	13 15
9	-	-		-		-	-	26 14
10	-	-		-		-	-	
11	-	-		-		-	-	
12	-	-		-		-	-	
13	-	-		-		-	-	
14 Aug.' 47	-	-		-		-	-	

* Weight of 1 plant only.

After the 9th lifting, 14th May, 1947, it was not possible to count stolons since there was no connection remaining between primary root and stem

No.1 N.Z. Pedigree White Clover.

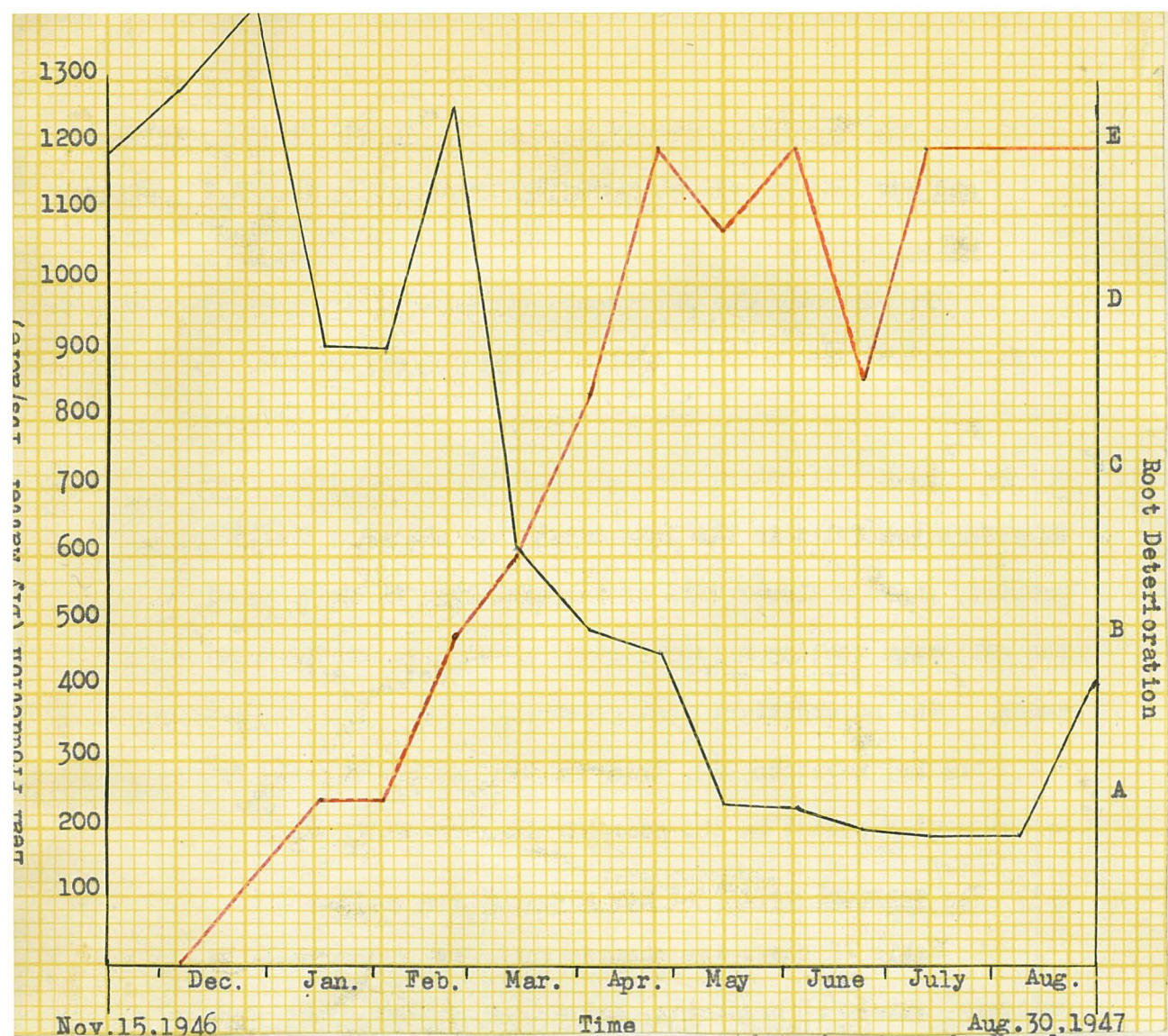
(i) Deterioration of the Primary Root system and New root development.

The seasonal deterioration of the primary root system follows the trend of that in the poor strain of white clover, both in time of onset of deterioration and complete deterioration. Both types of new rooting, crown and adventitious, were slower to begin growth.

TABLE X. Deterioration of Primary root system and new growth of roots in No. 1 N.Z. Pedigree white clover.

Lifting No.	Date	No. Plants/Pipe.	Colour of Primary root system.	Deterioration		New Rooting	
						No. crown roots/plant.	No. adventitious roots/stolon
1	15/11/46	2	White	-	-	-	2
2	6/12/46	2	"	-	-	-	2
3	17/1/47	1	"	A	-	9	4
4	4/2/47	2	Darkening	A	A	13	3
5	25/2/47	2	"	B	B	30	3
6	15/3/47	2	Light Brown	B	C	70	12
7	5/4/47	2	Brown	C	D	97	22
8	28/4/47	1	-	E	-	47	47
9	14/5/47	2	-	D	E	23	70
10	4/6/47	1	-	E	-	20	69
11	24/6/47	2	-	B	E	-	68
12	13/7/47	2	-	E	E	-	49
13	4/8/47	2	-	E	E	-	59
14	30/8/47	2	-	E	E	-	65

The amount of crown rooting approximated that in the poor strain of white clover, but after April, 1947, each observation showed the No.1 white clover to have more adventitious roots per stolon than the poor strain.



Nov. 15, 1946 Time Aug. 30, 1947
 Figure 10a. Leaf production and primary root deterioration in No. 1 N.Z. Pedigree white clover.
 — leaf production: — deterioration.

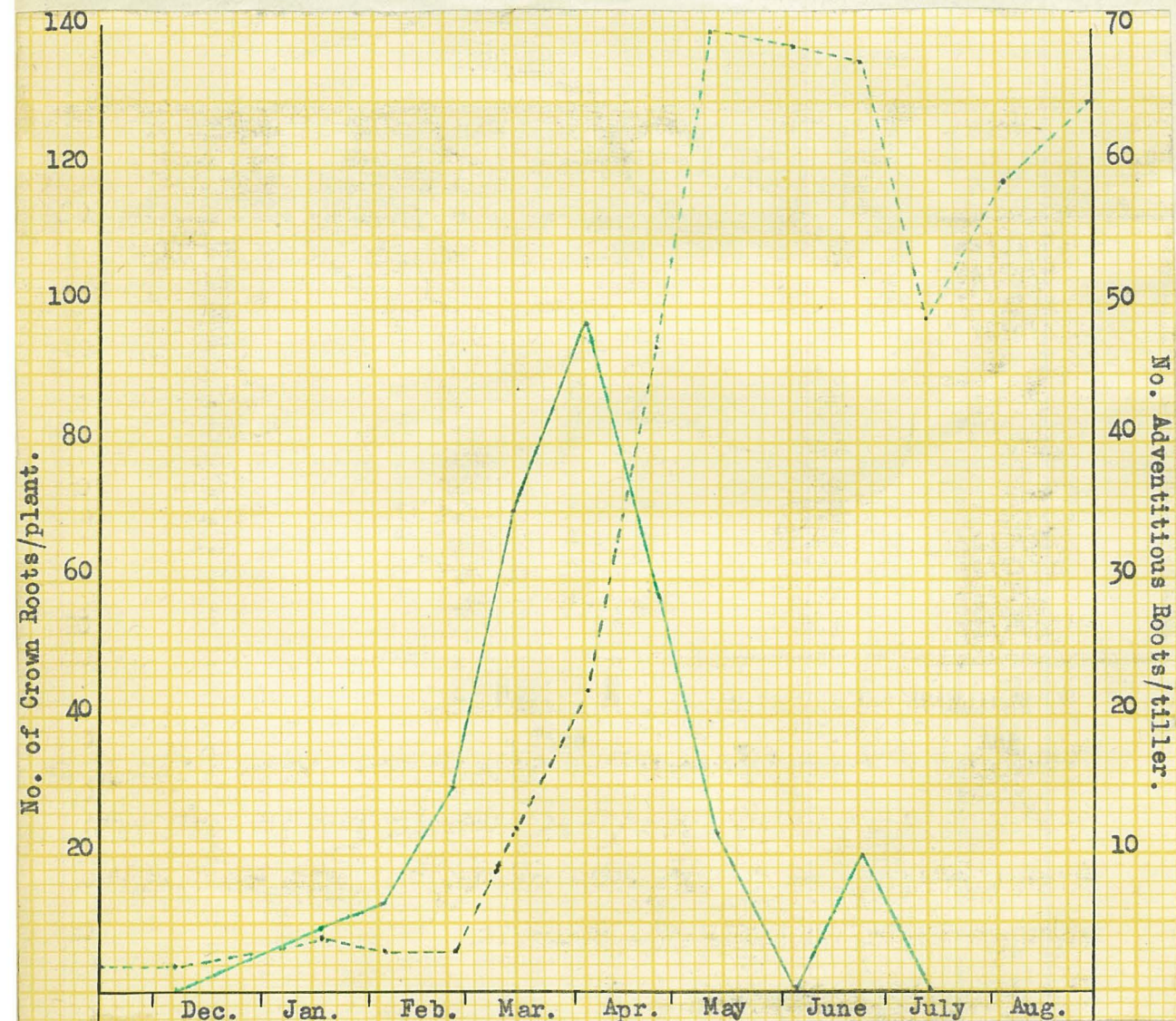


Figure 10b. New rooting in No. 1 N.Z. Pedigree white clover.
 — crown roots: - - - adventitious roots.

(ii) The relationship of deterioration of the primary root system and new root growth to seasonal production in No.1 N.Z. pedigree white clover.

Figures 10a and 10b compare graphically the seasonal production of No.1 N.Z. pedigree white clover with primary root deterioration and new root growth of that strain. The comparison is similar to that in the poor strain of white clover. Deterioration and new growth increases as production falls in the late autumn and winter. Deterioration, however, shows a slower rate of increase than in the poor strain, and the new crown rooting in complement, shows a slower decrease after March. The adventitious root growth line shows a more stable rise, but there is, nevertheless, irregularity in the latter part of the curve, as was most apparent in the poor strain of white clover.

(iii) The seasonal growth of new adventitious roots.

Table VI shows the changes that were apparent in length and diameter, extent of branching, and weight of new adventitious roots through the period of the trial.

TABLE XI. Seasonal growth of adventitious roots of No.1 N.Z. pedigree white clover.

Lifting No.	Date	Length of Longest new root observed.	Extent of Branching.	Diameter of largest new root observed.	Weight of new roots. 2 plants.
1	15/11/46	$\frac{1}{2}$ "	-	.3 m.m.	1.4 gms
2	6/12/46	2"	-	.4 "	2.7 "
3	17/1/47	2.5"	1st order	.8 "	* 4.6 "
4	4/2/47	4"	2nd "	1.1 "	8.8 "
5	25/2/47	8.5"	2nd "	1.7 "	12.5 "
6	15/3/47	7.5"	3rd "	1.9 "	8.8 "
7	5/4/47	9"	2nd "	3.3 "	13.4 "
8	28/4/47	10"	3rd "	2.6 "	* 9.9 "
9	14/5/47	12"	" "	2.8 "	16.0 "
10	4/6/47	9.5"	" "	2.4 "	* 12.4 "
11	24/6/47	10.5"	" "	3.4 "	9.1 "
12	13/7/47	11"	" "	3.5 "	13.2 "
13	4/8/47	12.5"	Some 4th	2.8 "	10.9 "
14	30/8/47	14"	"		

* indicates weight of roots of 1 plant only.

The weights of the new roots of No.1 white clover are greater than those of ordinary white clover. This is in conformity with the numbers of adventitious roots of the respective strains, No.1 white having more roots per stolon than the poorer strain.

(iv) Root hair development.

Root hair concentration was greatest in the primary root

system on the branches of the second order, and appeared to be greater than in ordinary white clover. This was unable to be proved by figures. There appeared to be a diminution after February when deterioration increased. On the adventitious roots, prior to branching (Nov. and Dec., 1946), development of root hairs was fairly strong, but with the development of branches, there was concentration on the branches of the first and second order and a definite diminution on the mains, until in the May (lifting 9) and subsequent liftings very few root hairs could be found on them.

(v) Other observations.

Data which showed little or no seasonal trends are presented in Table XII.

TABLE XII. Observations : Primary root system in N.Z. Pedigree white clover.

Lifting No.	Length of Primary root system.	Tap-root diameter.		No. laterals from tap-root.		Extent of Branching.	Weight of Primary root system. <u>2 plants.</u>	No. Stolons/ plant.	
		<u>m.m's</u>							
1 Nov. '46	20"	3.4	3.8	16	7	4th order	9.9 gms	15	19
2	21"	4.1	3.3	14	12	"	13.3	22	21
3	18"	3.0		14		"	* 10.9	17	
4	19"	3.1	6.0	6	13	"	6.8	19	22
5	18"	6.1	3.2	15	15	3rd	9.1	33	35
6	15"	3.4	4.2	12	30	4th	9.9	14	25
7	20"	6.2	2.8	20	19	3rd	12.8	14	29
8	-	-	-	10		-	* 1.0	19	
9	-	-	-	3	7	-	2.1	20	22
10	-	-	-	4		-	-	18	
11	-	-	-			-	-	-	-
12	-	-	-			-	-	-	-
13	-	-	-			-	-	-	-
14 Aug. '47	-	-	-			-	-	-	-

* Weight of one plant.

These measurements, as in ordinary white clover, could not be continued when the tap root had completely deteriorated and there was no longer connection between stolons.

C. COCKSFOOT.

The two features of seasonal root changes which were found to be of greatest interest were, as in the clovers, deterioration of the old root system and new growth. The nature of these differed, however, from that in the clovers, since in the later, the primary root system appears to persist for over a year (two years in the case of red clovers), and for the first year, the plant survives apparently on the primary system alone. The secondary or adventitious system in cultivated grasses is developed much earlier, and it is affected by deterioration rather differently from the primary root system of clovers. Deterioration of individual roots in cocksfoot begins by the sloughing off of the cortex near the point of attachment to the crown of the plant. Sloughing of the lower portions of the root then proceeds. Some of the roots may rot away then, but this could not be observed as in the clovers, since the root parts are so fine that any such deterioration is imperceptible. An attempt to assess the extent of survival of the old secondary root system is recorded in these results, the method used being indicated in Section III.

The amount of deterioration was measured by the number of roots whose cortex was sloughed, as a percentage of the total number of old adventitious roots. This measurement by no means gives a full picture of events, since different roots were at different stages of deterioration, i.e. the cortex was sloughed to a greater length of one root than another; and there was difficulty in separating individual roots by sampling to measure these stages, owing to the softness of the cortex remaining and its liability to damage.

New roots were easily recognised from sloughed roots by their thickness, and from old unsloughed roots by their comparative softness and colour, which was whiter and, in the early stages of development, shiny. New roots were formed mainly at the periphery of the root system, where new tillers appeared to be formed. For measurement, the number of new roots was taken as a percentage of total number of roots.

DANISH COCKSFOOT.

(1) Deterioration and new growth of roots.

The first plants of this strain were lifted on Nov.19, 1946, when the plants had been growing in the plots for 192 days. Already signs

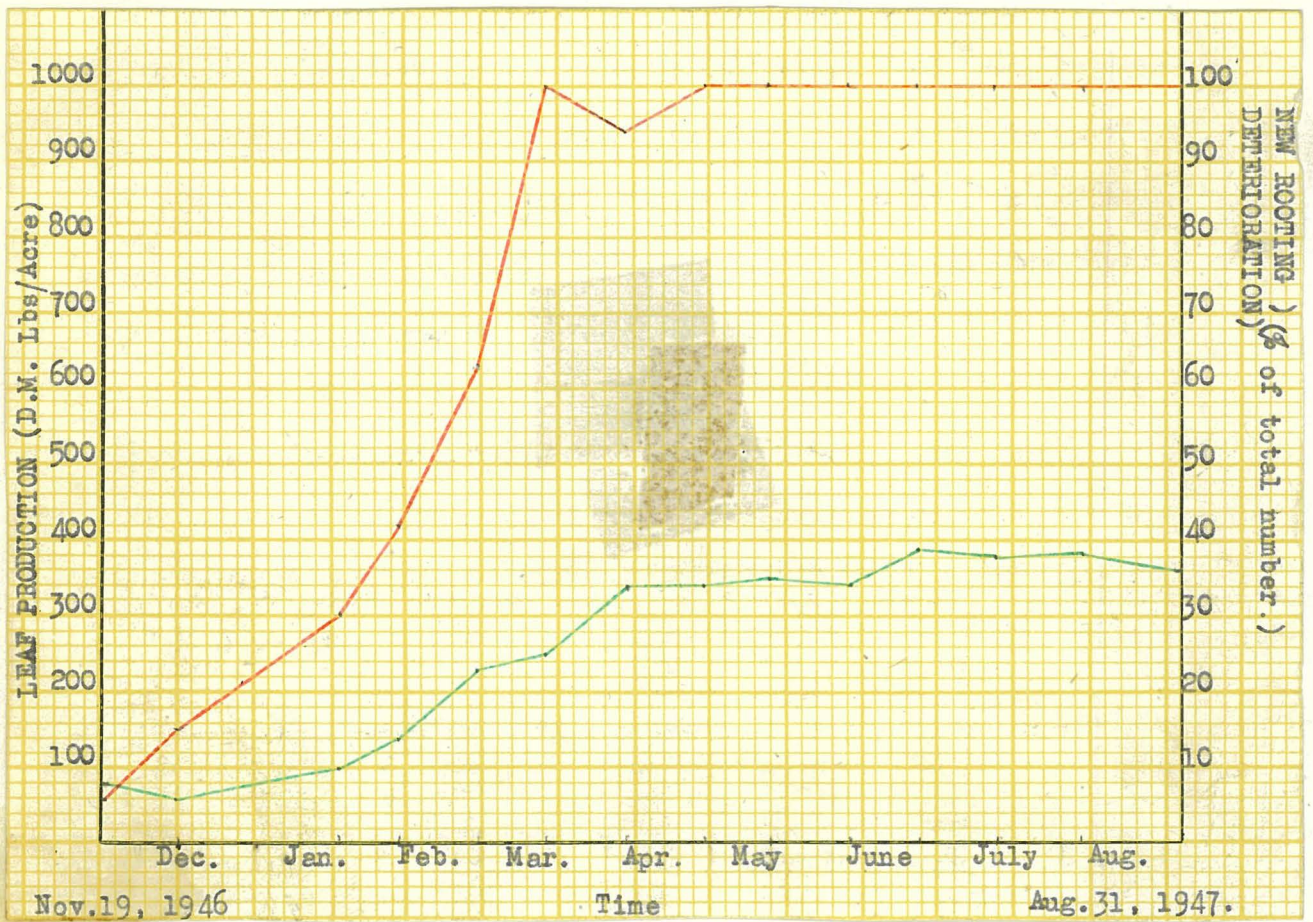


Figure 11. Deterioration and new growth of roots during the trial in Danish cocksfoot.

— root deterioration: — new root growth.

of new rooting and cortex sloughing in the old roots were obvious. Most of the new rooting appeared on the base of peripheral tillers of the plant which appeared to be new. This was in agreement with Jacques' observations in ryegrass (1937). In the liftings following, cortex deterioration, as affecting numbers of roots, intensified until in March 1947, all old roots were affected. In the early liftings, the cortex was sloughed only in the top few inches. In April and subsequently, the cortex was absent the entire length of the observable portions of the root. New roots increased fairly uniformly throughout the trial till at the end of August, 1946, 36% of the total roots counted were observed to be new. Table XIII shows both the increase in amount of deterioration and new rooting through the period of the trial.

TABLE XIII. Deterioration and new growth of adventitious roots in Danish cocksfoot.

Lifting No.	No. plants /pipe.	No. old adv. roots.	Roots affected by deteri.	% deteri. of old roots.	No. new roots.	Total No. roots.	New roots % of total roots.
1	3	518	31	6	44	532	8
2	3	437	65	15	28	465	6
3	3	555	167	30	63	628	10
4	3	673	281	42	109	782	14
5	3	531	334	63	159	690	23
6	2	321	321	100	107	428	25
7	3	378	355	94	198	576	34
8	2	306	306	100	156	462	34
9	3	340	340	"	182	522	35
10	3	394	390	"	200	594	34
11	3	353	353	"	226	579	39
12	3	362	262	"	224	586	38
13	3	299	299	"	182	481	38
14	3	298	298	"	169	468	36

(ii) The relationship of deterioration and new growth of roots to seasonal production.

No production figures of Danish cocksfoot in New Zealand are available, but the seasonal trend of production is reported to be similar to N.Z. cocksfoot, but earlier to begin growth in the late spring and falling off more rapidly in winter. Graphs of root deterioration and new growth are presented in figure 11 from columns 6 and 9 of Table XIII.

(iii) The seasonal growth of new roots.

Table XIV shows the growth of new roots through the period of the trial. There is a definite increase of new roots per tiller until April from whence there appears to be little change. The growth of new roots proceeds up to the last lifting, about 50% of new roots being over 6" in length.

TABLE XIV. Seasonal Growth of New Roots of Danish cocksfoot.

Lifting No.	No. new roots.	No. over 6" in length.	Extent of Branching.	No. tillers.	No. new root/ tiller.	Weight gms.	Diam. of largest new root. m.m.
1	44	-	-	84	.5	-	.7
2	28	-	1st order	55	.5	-	.6
3	63	-	1st "	59	1.1	.5	.9
4	109	13	1st "	97	1.1	.9	1.1
5	159	27	2nd "	71	2.2	1.7	1.2
6	107	20	2nd "	72	1.5	1.6	1.1
7	198	28	3rd "	106	1.9	2.1	1.0
8	156	39	3rd "	86	1.8	2.8	1.4
9	182	43	3rd "	105	1.7	4.0	1.1
10	200	74	4th "	84	2.4	6.2	1.2
11	226	81	3rd "	112	2.0	6.0	1.3
12	224	91	4th "	113	2.0	7.6	.9
13	182	79	3rd "	75	2.4	8.2	.9
14	169	82	4th "	66	2.6		

(iv) Survival of the adventitious root system.

Table XV presents the data from an attempt to find the survival of roots by a count method. The old roots, were separated from the new rooting and counted. The number of roots per tiller were thus determined for each observation made. There is a tendency for decrease in the number of roots per tiller, but there is considerable variations in the numbers, which cannot be accounted for statistically since there were insufficient numbers of plants lifted at each observation. Superficially, taking into account this data, and the number of new roots per tiller (Col.7, Table XIV), which appears to compensate the loss of the old roots at the final stages of the trial, there seems to be a 50% (approximately) replacement of deteriorated roots by new growth. There are, however, other factors to be considered later which would rather modify such a supposition.

TABLE XV. Survival of old Root System in Danish Cocksfoot.

No.	Date	No. surviving old roots.	No. tillers	No. roots/ tiller.
1	19/11/46	516	84	6.1
2	9/12/46	437	55	7.9
3	20/1/47	555	59	9.5
4	5/2/47	673	97	7.0
5	26/2/47	531	71	7.5
6	16/3/47	321	72	4.5
7	6/4/47	378	106	3.6
8	28/4/47	306	86	3.6
9	15/5/47	340	105	3.5
10	5/6/47	394	84	4.7
11	24/6/47	353	112	3.1
12	14/7/47	362	113	3.2
13	5/8/47	299	75	4.0
14	31/8/47	299	66	4.5

(v) Root hair development.

As in the clovers, no method was arrived at in assessing root hair numbers on the root parts. At the first observations, root hair development was concentrated on the main roots, while on the branches there was less concentration, the fourth order branches showing very sparse and often no development. There appeared to be a tendency for a decrease in root hair development especially on the main roots in the 4th observation (February 5, 1947) and this was progressive till May, when the cortex sloughing was general in the old root system, when no root hairs remained.

In the new adventitious roots, many root hairs were evident on the main roots from the 1st observation, mainly at the tips. In February, root hairs were plentiful on the branches, and development seemed to proceed generally throughout the trial. As in the old root system, root hairs were most concentrated on the mains, there being very few on the branches of the 4th order.

(vi) Other observations.

Measurements which were expected to yield further information on the seasonal growth of roots of Danish cocksfoot are shown in Table XVI. The diameters of the largest root found in each observation indicate a decrease after sloughing of the cortex in February, 1947, but no tendencies toward decrease in weight that might reasonably have been expected were found. This could have been attributable to at least two factors -

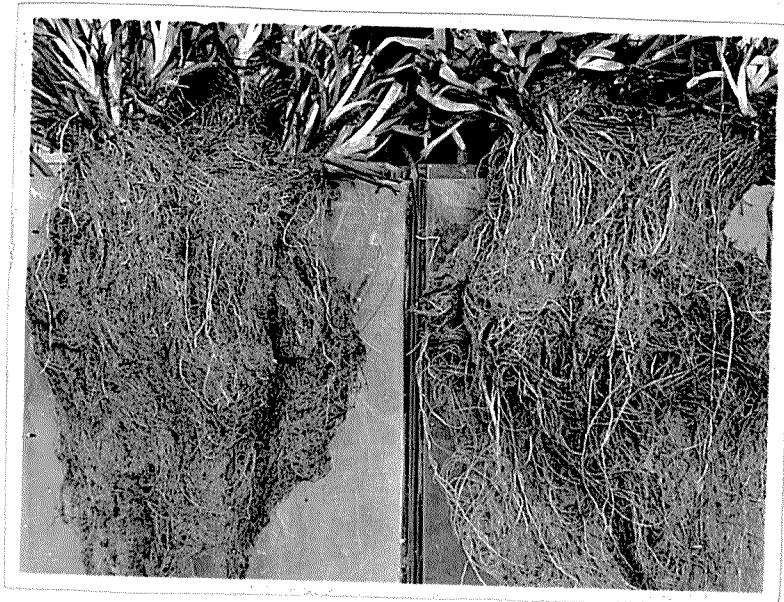


Figure 12. Comparison between new rooting of Danish and C23 cocksfoot. Danish cocksfoot (right) shows greater development in length and thickness of new roots at this stage. The new roots are recognizable from the old by their thickness and white colour.
(Photo taken May 10, 1947.)

(1) the influence of soil variation on the root growth of plants grown in different parts of the plot or (2) imperfect washing away of soil from the fine root parts.

TABLE XVI.

Lifting No.	Date	Length of root system. (Inches)	Extent of Branching in old root system.	Diameter of Largest white root in old system. (m.m.)	Weight of old root system. (gms.)
1	9/11/46	19	3rd	1.4	31.3
2	9/2/46	24	4th	1.6	25.7
3	20/1/47	21	"	1.2	30.0
4	5/2/47	19	"	1.2	41.3
5	26/2/47	21	"	.7	29.4
6	16/3/47	19	"	1.1	* 25.1
7	6/4/47	23	"	.7	39.1
8	28/4/47	20	"	.6	* 35.2
9	15/5/47	20	3rd	.4	42.0
10	5/6/47	19	"	.5	25.7
11	24/6/47	19	"	.4	20.8
12	14/7/47	17	"	.3	40.6
13	5/8/47	18	"	.4	34.1
14	31/8/47	20	"		

C.23 COCKSFOOT.

(i) Deterioration of old roots and new root growth.

Lifting of C.23 cocksfoot was begun at the same time as the Danish strain. There were marked differences in appearance between the roots of the two strains. The C.23 root parts were darker in colour, and much finer. Deterioration and new growth was not observed in the initial lifting and it was not until the 3rd lifting (20th January, 1947), that any was noted. By the 8th lifting (28th April, 1947), all components of the old root system showed sloughing of the cortex, indicating that deterioration approximating that in Danish cocksfoot.

New growth was similar to that recorded in the Danish strain, but was much slower growing in the early stages, both in diameter and length. Figure 12 shows the difference between new rooting in the two strains in May 1947.

Deterioration and new growth of roots is presented in Table XVII.

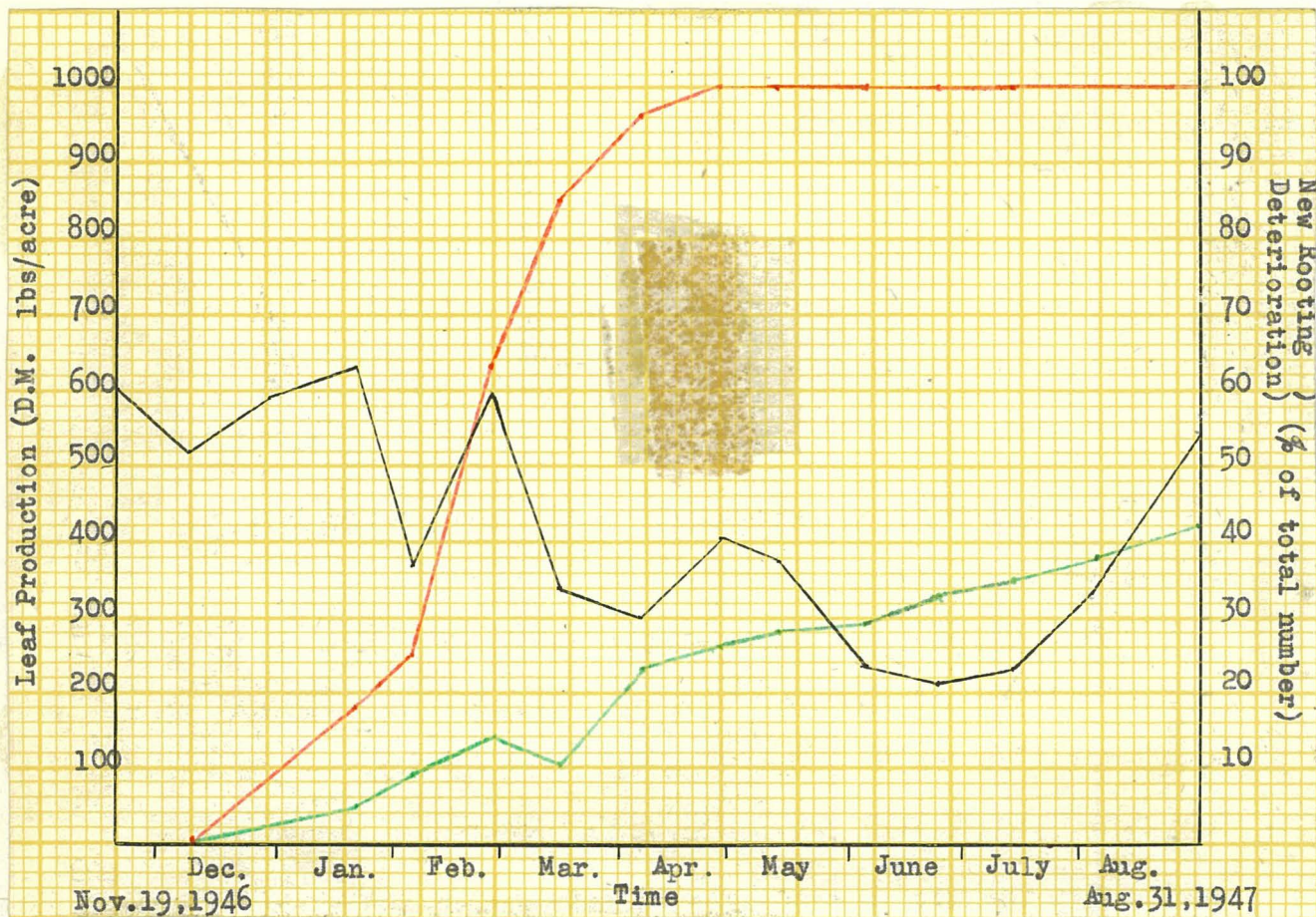


Figure 13. Comparison of seasonal leaf production with deterioration and new growth of roots in C.23 cocksfoot.

- leaf production.
- root deterioration.
- new root growth.

TABLE XVII. Deterioration and new growth of adventitious roots in
G.23 cocksfoot.

Date	No. plants /pipe.	No. old adv. roots.	Roots affec- ted by determ.	% Determ. of old roots.	No. new roots.	Total No. roots.	New roots % total.
19/11/46	3	582	-	-	-	582	-
9/12/46	3	380	-	-	-	380	-
20/1/47	3	346	62	18	18	364	5
5/2/47	3	783	183	25	74	817	9
26/2/47	3	603	381	63	88	691	14
16/3/47	3	689	557	85	77	766	10
6/4/47	3	604	572	96	176	780	23
28/4/47	2	486	486	100	172	668	26
15/5/47	3	483	483	100	187	670	28
5/6/47	3	502	502	100	205	707	29
24/6/47	3	443	443	100	223	666	33
14/7/47	3	324	324	100	174	498	35
5/8/47	3	403	403	100	254	667	38
31/8/47	3	426	426	100	273	699	39

(ii) The relationship of deterioration and new growth of roots to seasonal production.

Fig. 13 shows the relationship of seasonal production to deterioration of the root system and new root growth. The seasonal production line is derived from data from the P.R.B. of trials conducted over the same period as this investigation (Appendix V). Deterioration begins with the fall in production in late summer, while new root growth shows a fairly steady rise through the winter.

(iii) Seasonal growth of new roots.

Table XVIII shows the progress of seasonal growth of new roots of G.23 cocksfoot. Although new roots are slower in making their appearance, the rate of growth is faster, since at the last lifting, the number and the proportion of roots over 6" in length approximate the corresponding numbers in Danish cocksfoot. The total number of roots is greater, but the number of new roots per tiller is fewer, due, perhaps to the greater number of new tillers formed. The same tendency of greater rate of growth after the late appearance of new roots is evident in the diameters. There appears to be a point reached after which there is no further increase in diameter and this is reached earlier in Danish cocksfoot.

TABLE XVIII. Seasonal Growth of New Roots of C.23 cocksfoot.

Date	No. new roots.	No. over 6" in length.	Extent of branching.	No. of tillers.	No. new roots/tiller.	Weight (gms).	Diameter of largest new root. (m.m.)
19/11/46	-	-	-	87	-		
9/12/46	-	-	-	74	-		
20/1/47	18	-	1	119	.2		.5
5/2/47	74	-	1	139	.5		.6
26/2/47	88	-	1	125	.7	.2	.7
17/3/47	77	-	2	158	.5	.3	.9
6/4/47	176	6	2	181	1.0	1.0	.8
28/4/47	172	21	2	124	1.3	.7	.7
15/5/47	187	39	3	161	1.2	1.3	1.2
5/6/47	205	56	3	198	1.0	2.4	1.0
24/6/47	223	68	3	236	1.0	3.3	1.0
14/7/47	174	101	3	239	.9	3.9	1.0
5/8/47	254	129	4	245	1.0	7.8	1.0
31/8/47	273	133	4	268	1.0		

(iv) Survival of the adventitious root system.

The numbers of old roots per tiller at each observation are shown in Table XIX. They show similar tendencies to those in Danish cocksfoot, i.e. There is a 50% reduction of numbers per tiller in C.23, but this is probably due to the greater amount of tillering in this strain.

TABLE XIX. Survival of adventitious root system of C.23.

No.	Total No. of roots.	No. New roots.	No. Surv. old roots.	No. tillers	No. roots/tiller.
1	582		582	87	6.7
2	380		380	74	5.1
3	364	18	346	119	2.9
4	817	74	733	139	5.3
5	691	88	603	125	4.7
6	766	77	689	158	4.4
7	780	176	604	181	3.3
8	668	172	486	124	3.9
9	670	187	483	161	2.9
10	707	205	502	198	2.5
11	666	223	443	236	1.9
12	498	174	324	239	1.4
13	667	254	403	245	1.6
14	699	273	426	268	1.6

(v) Root Hair Development.

Root hair development in C.23 cocksfoot, as far as could be ascertained, was similar to that in Danish cocksfoot. The maximum concentration was found on the main roots. It was not till the 6th

lifting (16th March, 1947) that there appeared to be a decrease in the number of root hairs on the main roots. Those on the branches appeared to show a corresponding decrease, until at the 8th lifting (April 28th, 1947), when there was complete sloughing of the cortex on all the old main roots, no root hairs were observed.

Root hair development on the new adventitious roots of the C.23 strain was similar to that in the Danish. With the later development of new roots, root hairs were later in appearing, but by April, development was similar in most respects to the Danish cocksfoot.

(vi) Other observations.

Table XX shows measurements taken which may have had some bearing on the seasonal nature of root growth. As in Danish cocksfoot, the diameter of the largest roots observed in the old root system shows a decrease when sloughing of cortex occurs, but the weights of the old root systems show no regular tendency.

TABLE XX.

Lifting No.	Date	Length of root system. (inches)	Extent of Branching in old system.	Diameter of largest white root. (old system) (m.m.)	Weight of old root system. (gms.)
1	9/11/46	17	4th	.9	43.6
2	9/2/46	21	4th	.8	28.8
3	20/1/47	19	"	1.0	40.0
4	5/2/47	18	"	.8	43.5
5	26/2/47	18	"	.9	29.6
6	16/3/47	18	"	.9	53.1
7	6/4/47	19	"	.8	42.4
8	28/4/47	20	"	.5	* 26.6
9	15/5/47	18	"	.5	31.3
10	5/6/47	17	3rd	.4	25.7
11	24/6/47	19	"	.4	45.4
12	14/7/47	16	4th	.2	35.3
13	5/8/47	17	"	.3	40.0
14	31/8/47	19	"		

* Weight of 2 plants only.

D. THE RYEGRASSES.

The four ryegrasses studied, namely perennial, Italian, short rotation and Western Wolths were all finer in root parts than cocksfoot. In both roots and tillers, they were more numerous. The nature of new growth was similar to that described in cocksfoot for all ryegrass species. Most new roots were found to originate from tillers at the periphery of the plant, and were easily recognisable by their thickness compared with the deteriorated roots, and their colour and softness.

While deterioration in the ryegrasses was also similar to that in cocksfoot, the cortex sloughing off to leave the stele exposed in the ground, it was not so sharply defined. The cortex in the early stages of deterioration did not always separate cleanly from the stele, but enclosed it loosely. Whether this is due to soil conditions, or is an inherent property of the root systems of ryegrasses is not known. It made the assessment of the extent of deterioration difficult, since excess handling of the root material tended to increase the actual measurement by disturbing the loose cortex; and it was not possible to count all the roots affected by this form of deterioration owing to the fineness of the root parts. When the cortex does separate from the stele, it does so from the upper portion of the root first, as was observed in cocksfoot.

Measurements of deterioration and new growth of the adventitious roots in the ryegrasses are made on the same basis as those in cocksfoot.

ITALIAN RYEGRASS.

(1) Deterioration and new growth of roots.

The first observations on the root system of Italian ryegrass were made on Nov. 20, 1946, when the plants had been growing in the plots for 193 days. No signs of root deterioration or new growth of roots was evident at this or the following two liftings of plants. At the fourth lifting in early February, some few roots displayed the quality that has been defined as "deterioration", i.e. sloughing of cortex. However, a great number of other roots were very soft, and the cortex was easily removed by light rubbing of individual roots in the fingers. Previously it was more difficult to remove the cortex. There was a sudden increase



Figure 14. Comparison of seasonal leaf production with deterioration and new growth of roots in Italian ryegrass.

- leaf production.
- root deterioration.
- new root growth.

(both numerically and proportionately with the number of old roots surviving) between March and April, 1947, of deteriorated roots. Previously the cortex sloughed off only on the 3-4 inches of the roots near the point of attachment to the tillers, but now this condition appeared to extend over the observable length of the root. At the last observations made (August, 1947), over 70% of the number of old adventitious roots remaining on the plants exhibited cortex deterioration. Of the remainder, most showed the soft condition described previously, and it is possible with further observations, that 100% root deterioration, as attained by the two strains of cocksfoot, may have been observed.

New root growth was first observed in the fifth lifting (late February), and showed a steady increase to reach almost 60% of the total number of roots at the last observation in August, 1947.

Table XXI shows the data relevant to deterioration and new growth of roots in Italian ryegrass.

TABLE XXI. Deterioration and new growth of the adventitious root system in Italian ryegrass.

Date	No. Plants /pipe.	No. old adv. roots.	Roots affected to Detern.	% Detern. of old roots.	No. new roots.	Total No. Roots.	New roots % of total roots.
20/11/46	3	597	-	-	-	597	-
22/1/46	3	714	-	-	-	714	-
23/1/46	3	462	-	-	-	462	-
6/2/47	2	636	7	1	-	636	-
27/2/47	2	661	13	2	65	726	9
18/3/47	2	568	74	13	84	652	13
7/4/47	3	468	281	60	70	538	13
29/4/47	3	470	259	55	192	662	29
16/5/47	3	602	361	60	271	873	31
5/6/47	1	183	122	66	86	269	32
26/6/47	3	401	281	70	291	692	42
14/7/47	2	222	160	72	262	484	54
5/8/47	3	255	186	73	324	579	56
31/8/47	1	89	67	76	128	217	59

(ii) The relationship of deterioration and new growth of roots to seasonal production.

Fig.14 attempts to relate the deterioration and new growth of roots, in the form of graph curves, observed in this trial to a typical production curve of Italian ryegrass. This latter curve derived from yield trial data from the Plant Research Bureau, (Appendix VI), however, does not give a true representation of the relationship, for the following

reasons:

1. The data is the result of trials made in 1945-46, and as in the case of the red clovers, does not give a result which can be directly compared with root data obtained in 1946-47.
2. Since Italian ryegrass is an annual pasture plant, dry matter figures in the P.R.B. trial were considered only during the period of the year that the grass is utilised as such (April 1945 - February 1946). Thus the line between February and May on the production curve in Fig.14 is merely a connecting link between productions at different seasons.
3. The production curve represents the production in the first year, while data on root changes were obtained in the second year of the life of the plants.

From the limitations that have been outlined, it is obvious that the comparison between production and the seasonal root behaviour of Italian ryegrass as pictured by Fig.14 is not a real one. The only observation that can be made is that there is a tendency for increase in deterioration of the old root system and new root growth with the fall in production in the autumn.

(iii) The seasonal growth of new roots.

Table XXII shows data for the progress of growth of new roots through the trial.

TABLE XXII. Seasonal growth of new roots in Italian ryegrass.

Date	No.new roots.	No.over 6" in length.	Extent of Branching	No. tillers.	No.new roots /tiller.	Weight gms.	Diameter largest new root. m.m.
20/11/46	-	-	-	133	-	-	-
12/12/46	-	-	-	187	-	-	-
23/1/47	-	-	-	230	-	-	-
6/2/47	-	-	-	219	-	-	-
27/2/47	65	-	-	164	.4	-	.3
18/3/47	84	-	-	137	.6	.5	.3
7/4/47	70	17	-	74	1.0	.7	.4
29/4/47	192	36	1st order	137	1.4	1.8	.6
16/5/47	271	44	1st "	246	1.1	1.9	.8
5/6/47	86	24	1st "	88	1.0	2.0	.8
26/6/47	291	91	2nd "	264	1.1	4.0	.7
14/7/47	262	102	2nd "	166	1.6	3.6	.8
5/8/47	324	129	3rd "	221	1.5	8.4	.7
31/8/47	128	46	3rd "	79	1.3	-	-

Branching was much slower than in cocksfoot, where branches of the 4th order

were observed in the last observations. Numbers of new roots per tiller were significantly fewer than in cocksfoot, due to the greater numbers of tillers in Italian ryegrass, since numbers of new roots were comparable between the two. Weight measurements showed increase through the trial, and diameters showed increase up until April, after which they remained fairly constant.

(iv) Survival of the adventitious root system.

The numbers of old roots per tiller surviving at each observation are shown in table XXIII. From these it appears that there is a gradual loss of roots from November till August in the next year, until there is almost a 70% reduction in the number of old roots surviving per tiller. This implication will be discussed later in Section V.

TABLE XXIII. Survival of the old root system in Italian ryegrass.

Lifting No.	Date	No. surviving old roots.	No. tillers	No. roots/ tiller.
1	20/11/46	597	193	3.9
2	12/12/46	714	187	3.8
3	23/1/47	462	136	3.4
4	6/2/47	636	219	2.9
5	27/2/47	661	264	2.5
6	18/3/47	568	191	2.9
7	7/4/47	468	204	2.3
8	29/4/47	470	177	2.6
9	16/5/47	602	246	2.4
10	5/6/47	183	88	2.1
11	26/6/47	401	264	1.5
12	14/7/47	222	166	1.3
13	5/8/47	255	221	1.2
14	31/8/47	89	79	1.1

(v) Root hair development.

At the first three observations, root hairs were evident along the length of all main roots, concentration being heaviest at the top 1-3 inches and, in the case of the shorter roots (on which the tips were available for inspection), at about $\frac{1}{2}$ inch from the tips for about 1 inch. It was difficult after the 5th lifting (February) to find the root hair concentration at the tips owing probably to elongation of the roots, but there seemed to be a decrease in concentration over all the old root system. On the roots whose cortex seemed to be softened prior to sloughing, only very few root hairs were seen.

Even at the first sign of new rooting (27th February, 1947),

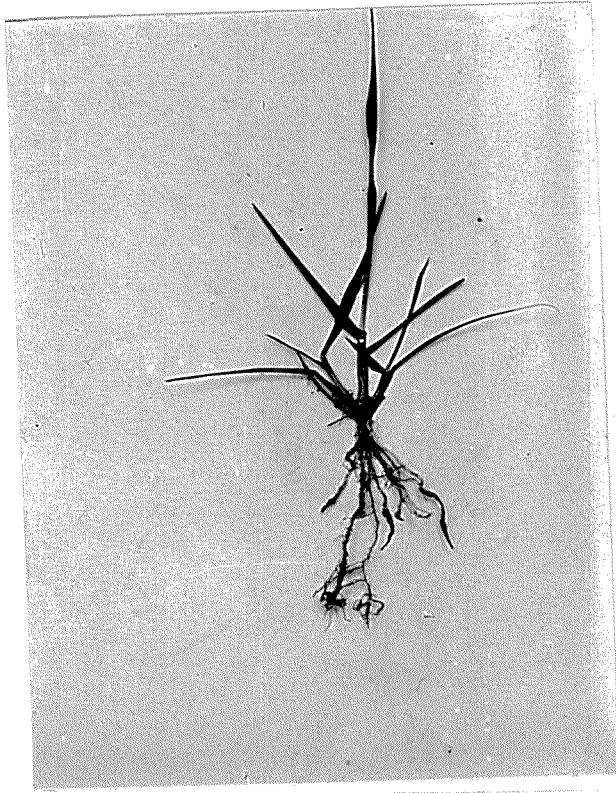


Figure 15. Young tillers from the periphery of a Western Wolth's plant showing new rooting.
(Photo taken May 16, 1947.)

root hairs were evident on the new roots. There was fairly even distribution until May when branching was first observed on the new main roots. High concentration then appeared to become localised, as in the old main roots, at the tips and top portions of the roots. Development on the branches was sparse until July when many hairs were observed on the 1st order branches. There was little development on the 2nd order branches.

(vi) Other observations.

Table XXIV shows data to which little seasonal significance could be attached. The weights of roots at the different liftings show a general tendency for decrease in weight with deterioration of the root system, but since this tendency is evident in only one other grass (Western Wolths), it cannot be emphasised in this case.

TABLE XXIV. Measurements of the old adventitious roots in Italian ryegrass.

Lifting No.	Date	Length of root system (inches)	Extent of Branching in old system.	Diameter of largest white root. (m.m.)	Diameter of sloughed roots. (m.m.)	*Weight of old root system. (gms).
1	20/11/46	19	3rd order	.7	-	50.7
2	12/12/46	23	4th "	.6	-	30.7
3	23/1/46	22	4th "	.8	-	44.6
4	6/2/47	18	4th "	.7	.3	26.3 (2)
5	27/2/47	22	4th "	.7	.4	27.1 (2)
6	18/3/47	18	4th "	.7	.4	26.6 (2)
7	7/4/47	18	4th "	.8	.4	21.4
8	29/4/47	18	4th "	.8	.3	14.6
9	16/5/47	18	4th "	.9	.4	22.9
10	5/6/47	19	4th "	.8	.3	10.0 (1)
11	26/6/47	18	4th "	.8	.3	14.3
12	14/7/47	16	4th "	.9	.4	6.8 (2)
13	5/8/47	17	3rd "	.7	.3	15.6
14	31/8/47	18	3rd "			

* Weights of 3 plants except where brackets indicate the number of plants weighed.

WESTERN WOLTHS RYEGRASS.

(i) Deterioration and new growth of roots.

Observations on the root system of Western Wolths ryegrass were made at the same time as those on Italian ryegrass. The nature of deterioration was similar to that in the latter, but was considerably later in showing actual sloughing of the cortex from the roots. At the 4th

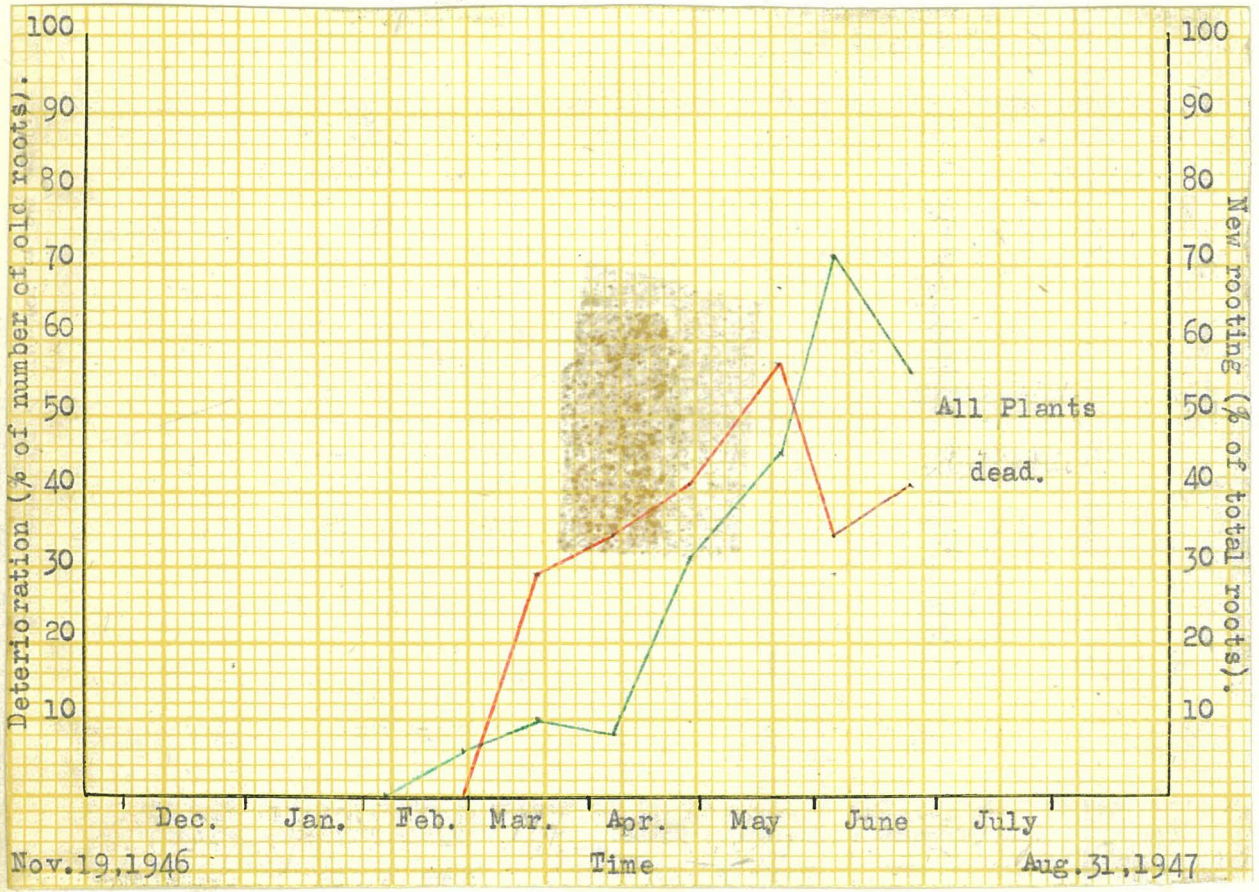


Figure 16. Deterioration and new growth of roots in Western Wolths.
 — root deterioration: — new root growth.

Why do the plants die when there are so many new roots.

lifting (Feb. 6, 1947), however, it was noticed that many of the old roots were soft and their cortex was easily removed. It was not until March 18, that sloughing of the cortex was noted. After this lifting, there was not a great increase in the percentage of old roots showing deterioration in the form of cortex sloughing, but cortex of the roots not showing this condition was mostly soft, and easily detachable.

TABLE XXV. Deterioration and new growth of adventitious root system in Western Wolths ryegrass.

Date	No. Plants /pipe.	No. old adv. roots.	Roots affected by Detern.	Determ. % of old roots.	No. new roots.	Total No. roots.	New roots % of total.
20/11/46	3	389	-	-	-	389	-
12/12/46	3	278	-	-	-	278	-
23/1/46	3	562	-	-	-	562	-
6/2/47	1	256	-	-	-	256	-
27/2/47	3	332	-	-	23	355	6
18/3/47	1	114	33	29	12	126	10
7/4/47	3	303	105	34	29	332	8
29/4/47	3	166	68	41	74	240	31
16/5/47	3	158	91	57	129	287	45
5/6/47	2	57	19	34	139	196	71
26/6/47	2	107	44	41	137	244	56
14/7/47	All plants died out after this lifting.						
5/8/47							
31/8/47							

New rooting was observed to begin in February at the 5th lifting and the increase proportionate to the total number of roots was more rapid than in Italian ryegrass, until the death of the remainder of the Western Wolths plants in the plots after the 11th lifting.

Data concerning deterioration and new growth of roots in Western Wolths is presented in table XXV.

(ii) The relationship of deterioration and new growth of roots to seasonal production.

No figures for the seasonal production of Western Wolths were available for comparison with seasonal root behaviour.

The plants died out in the winter, being well into the second year of growth, and up to the time of dying out, deterioration and new rooting were observed as in the other grasses. Fig. 16 graphs these two seasonal root changes. This is discussed in a following section.

(iii) The seasonal growth of new roots.

Table XXVI shows the seasonal growth changes of the new

roots through the trial period. Branching was similar to that in Italian ryegrass, and weight of the new roots and diameters showed increases from initial measurements. The numbers of new roots per tiller were very low. This was due to the surprising number of tillers at all observations, which may have been induced by the lenient treatment of clipping, a reaction that Jacques (1937) found in Italian ryegrass. However the tillers were mainly very weak, unlike those in the other ryegrasses, and after the plants had been clipped in late June, no recovery was seen in any of the remaining plants at subsequent liftings.

TABLE XXVI. Seasonal growth of new adventitious roots in Western Wolths ryegrass.

Date	No. new roots.	No. over 6" in length.	Extent of Branching.	No. of Tillers.	No. New roots/ tiller.	Weight gms.	Diameter of largest new root. m.m.
20/11/46	-	-	-	86	-	-	-
12/12/46	-	-	-	128	-	-	-
23/1/47	-	-	-	133	-	-	-
6/2/47	-	-	-	82	-	-	-
27/2/47	23	-	-	114	.2	.1	.3
18/3/47	12	-	1st order	61	.2	-	.3
7/4/47	29	-	1st "	106	.3	.3	.4
29/4/47	74	22	1st "	173	.4	1.0	.7
16/5/47	129	49	2nd "	224	.2	2.2	.8
5/6/47	139	48	2nd "	192	.3	2.4	.7
26/6/47	137	62	2nd "	234	.3	2.6	.7

(iv) The survival of the adventitious root system.

Table XXVII shows the number of old roots per tiller surviving at each lifting. As was the case in Italian ryegrass, there was a gradual reduction in this number with successive liftings.

TABLE XXVII. Survival of the old root system in Western Wolths ryegrass.

Lifting No.	Date	No. surviving old roots.	No. tillers	No. roots/ tiller.
1	20/11/46	389	86	4.5
2	12/12/46	278	128	2.2
3	23/1/47	562	133	4.2
4	6/2/47	256	82	3.1
5	27/2/47	332	114	2.9
6	18/3/47	114	61	1.9
7	7/4/47	303	106	2.8
8	29/4/47	166	173	1.0
9	16/5/47	158	224	.7
10	5/6/47	57	192	.3
11	26/6/47	107	234	.5

There was a greater difference between the numbers of surviving roots per tiller at the first liftings and at the last

than was the case in Italian ryegrass.

(v) Root hair development.

Root hair development was somewhat similar to that observed in Italian ryegrass, but there appeared to be less concentration on all root parts. Reduction in concentration of root hairs on the old adventitious roots occurred at the same lifting as in Italian ryegrass (February), but on the new roots, root hair development was not evident till March, three weeks after it had been observed in Italian ryegrass, although the time of onset of new rooting was simultaneous.

(vi) Other observations.

Observations made which seemed to have little bearing on the seasonal root growth of Western Wolths are included in table XXVIII. As was noted in Italian ryegrass, there appears to be a tendency for a decrease in weight with the intensification of the deterioration of the old root system.

TABLE XXVIII. Measurements of old adventitious roots in Western Wolths.

Lifting No.	Date	Length of root system. (inches)	Extent of Branching.	Diam. of largest white root. (m.m.)	Diam. of sloughed roots. (m.m.)	* Weight of old root system. (gms.)
1	20/11/46	17	2 nd order	.6	-	21.1
2	12/12/46	20	2 "	.6	-	18.8
3	23/1/46	18	2 "	.7	-	13.7
4	6/2/47	16	3 rd "	.8	-	10.8 (1)
5	27/2/47	19	3 "	.8	-	17.9
6	18/3/47	18	3 "	.9	.5	7.1
7	7/4/47	19	3 "	.6	.4	16.0
8	29/4/47	16	3 "	.8	.4	6.8
9	16/5/47	16	3 "	.8	.3	5.2
10	5/6/47	14	3 "	.8	.3	8.4 (2)
11	26/6/47	16	3 "	.8	.4	8.8 (2)

* Weights for 3 plants except where number of plants indicated in brackets.

PERENNIAL RYEGRASS.

(i) Deterioration and new growth of roots.

First liftings of perennial ryegrass plants for root observation were made on Nov. 19, 1946, when the plants had been growing in the plots for 192 days. No signs of root deterioration or new growth was noted. Some new rooting was recognised at the third lifting (Jan 24, 1947)

and in subsequent liftings the proportion of new roots to the total number of roots increased until at the last lifting (Aug.31, 1947), new roots numbered 40% (approx.) of the total number of roots.

Deterioration of the old adventitious roots was first observed at the 5th lifting (Feb.28) and while the number of roots exhibiting actual sloughing of the cortex was small, there was a fairly general distribution of roots which appeared to be in the early stages of deterioration. In the roots which showed cortex sloughing, this was confined mainly to the top few inches of the root. In the liftings following, the numbers of roots affected increased, and the sloughing extended the length of most of the roots affected at lifting 10 (June 5).

On the roots remaining, many showed softening of the cortex in latter liftings, but it was not possible to give any accurate assessment of the numbers thus affected. If the trial could have been carried on further, it is possible that a greater percentage of deterioration would have been observed.

Table XXIX shows data relevant to deterioration and new growth of roots in perennial ryegrass.

TABLE XXIX. Deterioration and new growth of the adventitious root system in perennial ryegrass.

Date	No.plants /pipe.	No.old adv. roots.	Roots affected by Detern.	Detern. % of old roots.	No.new roots.	Total no. roots.	New roots % total roots.
19/11/46	3	824	-	-	-	824	-
10/12/46	3	677	-	-	-	677	-
24/1/47	3	664	-	-	73	671	11
7/2/47	3	959	-	-	129	988	13
28/2/47	2	684	7	1	113	751	15
18/3/47	3	807	16	2	185	967	19
8/4/47	3	824	107	13	202	1018	20
30/4/47	2	521	198	38	108	636	17
17/5/47	3	792	318	40	176	978	18
5/6/47	3	683	316	46	164	864	19
27/6/47	2	923	470	51	413	1215	34
15/7/47	3	792	413	52	412	1116	37
6/8/47	2	583	298	51	375	989	38
31/8/47	3	552	294	53	437	1067	41

(ii) The relationship of deterioration and new growth of roots to seasonal production.

Figure 17 illustrates the relationship of deterioration of the old root system and new adventitious root growth to leaf growth as

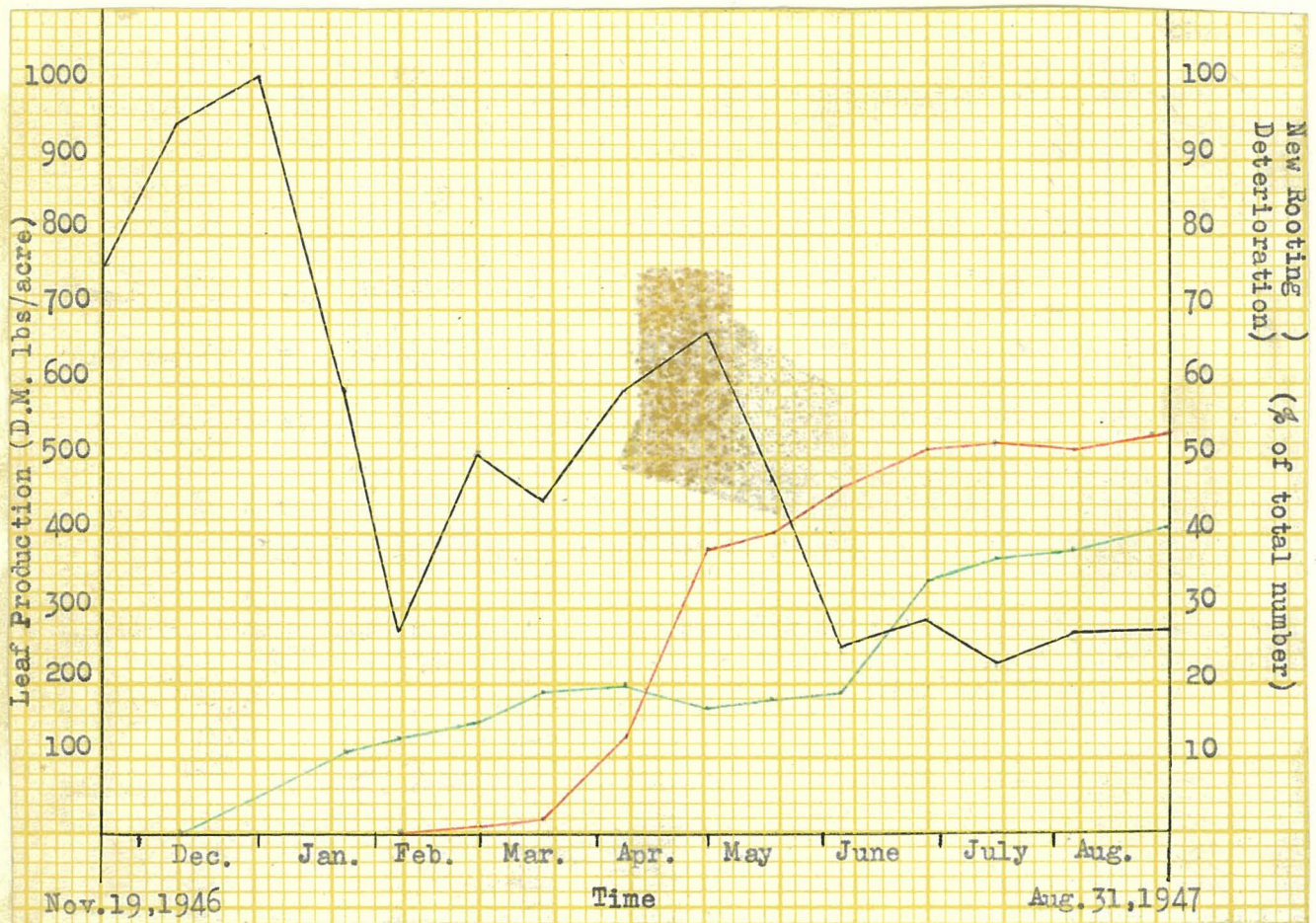


Figure 17. Comparison of seasonal leaf production with deterioration and new growth of roots in perennial ryegrass.

- leaf production.
- root deterioration.
- new root growth.

represented by a production graph from yield trial data over the same period as this trial obtained from the P.R.B. (Appendix VII). On comparing the production and deterioration lines in fig.17, it can be seen that deterioration of the root system begins in the autumn with the rise in leaf production. At the flush of leaf growth in the autumn, deterioration accelerates and proceeds, as the production falls towards winter. New growth of roots shows a steady increase from January onwards, and may possibly reach its maximum in spring with the onset of leaf growth.

(iii) Seasonal growth of new roots.

The various measurements that show seasonal changes in the growth of new roots is recorded in Table XXX. New roots appear earlier than in Italian ryegrass, and this may account for the more extensive branching in perennial ryegrass.

TABLE XXX. Seasonal growth of new roots in perennial ryegrass.

Date	No.new roots.	No.over 6 ⁿ in length.	Extent of branching.	No.of tillers.	No.new roots/tiller.	Weight gms.	Diameter largest new root. m.m.
19/11/46	-	-	-	317	-	-	-
10/12/46	-	-	-	289	-	-	-
24/1/47	73	-	-	287	.3	-	.4
7/2/47	129	-	-	341	.4	-	.5
28/2/47	113	-	-	274	.4	.2	.5
18/3/47	185	-	1 st order	291	.6	.4	.4
8/4/47	202	32	1 "	252	.8	.7	.8
30/4/47	108	21	2 nd "	288	.4	.5	.7
17/5/47	176	39	2 "	403	.4	1.1	.8
5/6/47	164	55	2 "	496	.3	1.7	.8
27/6/47	413	78	2 "	529	.8	4.4	.7
15/7/47	412	97	3 rd "	540	.8	7.1	.8
6/8/47	375	131	3 "	402	.9	7.8	.9
31/8/47	437	246	3 "	514	.9		

The weights and diameters of the new roots show somewhat similar increases, but the number of new roots per tiller is significantly lower. Since winter production is higher in perennial than in Italian ryegrass, and comparing the number of tillers of the two species at all observations in this trial, it would be reasonable to suppose that the low number of new roots per tiller may be attributable to more vigorous tillering in perennial ryegrass.

(iv) Survival of the adventitious root system.

Table XXXI shows the number of old roots per tiller surviving at each lifting. At the last lifting there appears to be about a 40% survival of old roots. There is a possibility that this is not the final survival figure, were the trial able to have been continued.

TABLE XXXI. Survival of old roots of perennial ryegrass.

Lifting No.	Date	No. surviving old roots.	No. tillers	No. roots / tiller.
1	20/11/46	824	317	2.5
2	12/12/46	677	289	2.3
3	23/1/47	664	287	2.3
4	6/2/47	959	341	2.8
5	27/2/47	684	274	2.5
6	18/3/47	807	291	2.8
7	7/4/47	824	252	3.3
8	29/4/47	521	288	1.8
9	16/5/47	792	403	1.9
10	5/6/47	683	496	1.4
11	26/6/47	923	529	1.7
12	14/7/47	792	540	1.5
13	5/8/47	583	402	1.5
14	31/8/47	522	514	1.0

(v) Root hair development.

Root hair development on the old adventitious roots was similar to that observed in Italian ryegrass. The root parts on which hairs were most concentrated were the same as in Italian ryegrass. Diminution in concentration was not observed on the old roots unaffected by cortex sloughing, until the 7th lifting (April 8), after which it was fairly general.

On the new roots, hair development was evident at the first lifting that new rooting was observed (Jan. 24, 1947). From this lifting, development was similar to that noted in Italian ryegrass, although after the 9th lifting (May 17), there appeared to be higher concentration or root hairs on all parts of roots.

(vi) Other observations.

Table XXXII presents data to which little significance could be attached.



Figure 18. Old tillers from a plant of short rotation ryegrass showing cortex sloughing of the old roots indicated by arrow.

(Photo taken June 5, 1947.)

TABLE XXXII. Measurements of old adventitious roots in Perennial ryegrass.

Lifting No.	Date	Length of root system (inches)	Extent of Branching.	Diam.largest white root. (m.m.)	Diam.of sloughed roots. (m.m.)	* Weight of old root system. (gms.)
1	19/11/46	18	3 rd order	.8	-	36.8
2	10/12/46	18	3 "	.8	-	29.7
3	24/1/47	18	3 "	.9	-	24.9
4	7/2/47	17	3 "	.9	-	52.1
5	28/2/47	17	4 th "	.9	.5	21.7(2)
6	18/3/47	19	4 "	.8	.5	30.2
7	8/4/47	17	4 "	.9	.4	46.5
8	30/4/47	17	4 "	.8	.4	20.6(2)
9	17/5/47	16	4 "	.7	.3	36.1
10	5/6/47	17	4 "	.9	.4	47.3
11	27/6/47	18	4 "	.8	.4	31.6(2)
12	15/7/47	18	4 "	.7	.3	26.8
13	6/8/47	18	3 rd "	.8	.3	21.0(2)
14	31/8/47	19	4 th "			

* Weights of 3 plants except where brackets indicate number of plants weighed.

SHORT ROTATION RYEGRASS:

(1) Deterioration and new growth of roots.

Liftings of short rotation ryegrass plants for root observations were made at the same times as those of perennial ryegrass. As in perennial ryegrass, new rooting was observed at the 3rd lifting (24th Jan, 1947), prior to any sign of root deterioration. At subsequent observations, the new roots showed a steady increase until at the last lifting they numbered 48% of the total number of roots.

Deterioration of the old adventitious roots was apparent at the same time as in perennial ryegrass, and the proportionate increases were much alike in the two grasses. The same difficulty of accounting for the roots whose cortex showed signs of deterioration without sloughing off was encountered, and there was the possibility that, were further observations able to be made in both grasses, the extent of deterioration in short rotation ryegrass may have differed from that in perennial ryegrass.

Table XXXIII presents data for deterioration and new growth of roots throughout the trial.

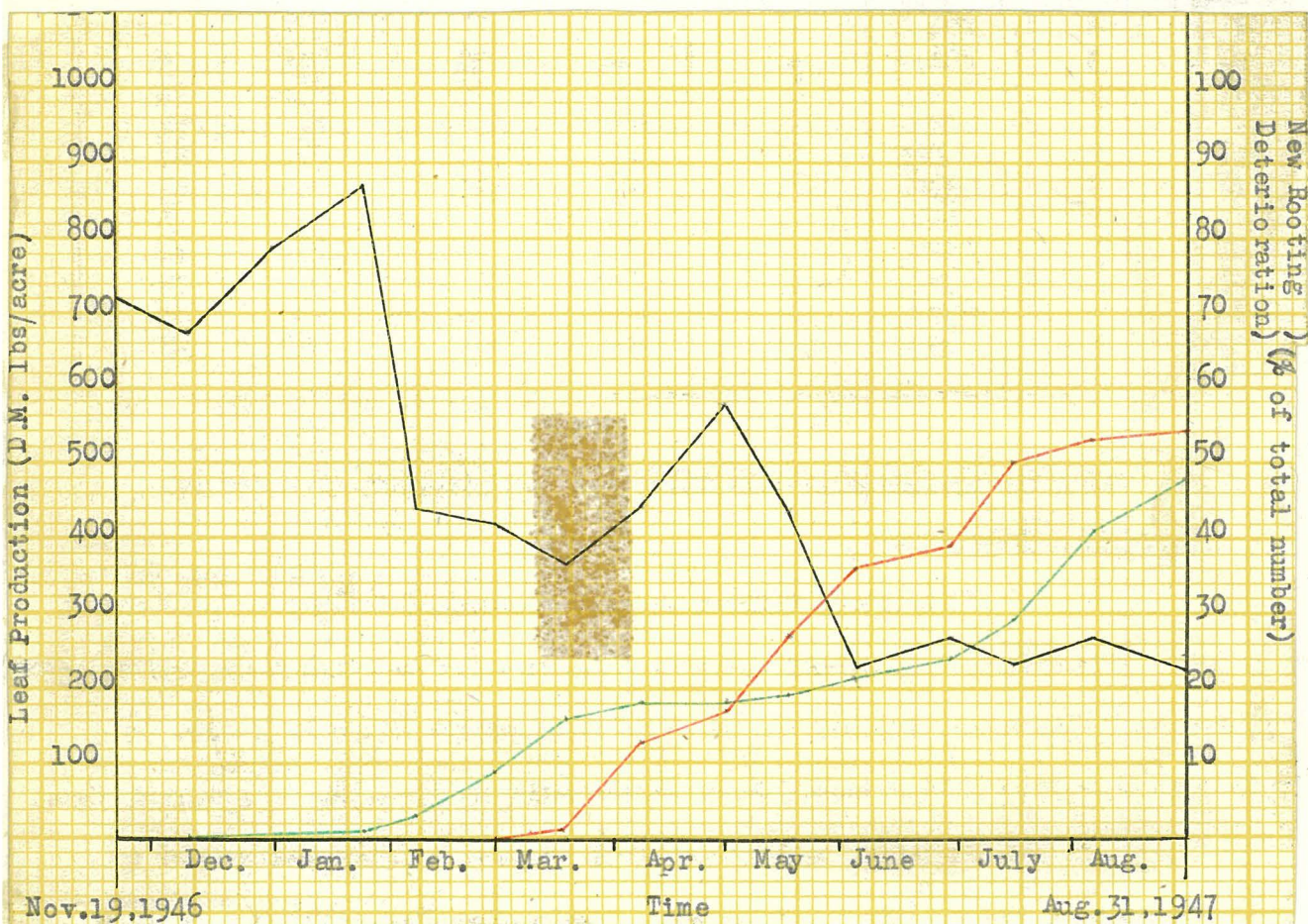


Figure 19. Comparison of seasonal leaf production with deterioration and new growth of roots in short rotation ryegrass.

- leaf production.
- root deterioration.
- new root growth.

TABLE XXXIII. Deterioration and new growth of the adventitious roots in short rotation ryegrass.

Date	No. plants / pipe.	No. old adv. roots.	Roots affected by Determ.	Determ. % of old roots.	No. new roots.	Total no. roots.	New roots % total.
19/11/46	3	911	-	-	-	911	-
10/12/46	3	766	-	-	-	766	-
24/1/47	2	628	-	-	6	634	1
7/2/47	2	464	-	-	14	478	3
28/2/47	3	720	-	-	71	791	9
18/3/47	1	494	6	1	95	589	16
8/4/47	2	710	92	13	156	866	18
30/4/47	2	429	73	17	96	525	18
17/5/47	3	675	182	27	158	833	19
5/6/47	2	466	134	36	98	464	21
27/6/47	3	576	225	39	182	758	24
15/7/47	3	459	232	50	153	612	29
6/8/47	1	212	109	53	148	360	41
31/8/47	2	280	151	54	257	537	48

(ii) The relationship of deterioration and new growth of roots to seasonal production.

Fig. 19 illustrates the relationship of seasonal production of short rotation ryegrass and root deterioration and new root growth. With the onset of the autumn flush of leaf growth there is a rise in the amount of root deterioration which tends to increase after production falls towards winter. New root growth increases from late summer throughout the period of the trial. The derivation of the production curve is shown in Appendix VIII.

(iii) The seasonal growth of new roots.

Table XXXIV shows the progress of growth of new roots through the period of the trial. Branching follows that in perennial ryegrass, there being branches of the third order at the last lifting. The number of new roots per tiller is, up to the 14th lifting, much lower than the corresponding figure in perennial ryegrass. The last figure of .8 new roots per tiller may be an indication that new rooting is slower in approaching that of perennial ryegrass numerically. Only further observations could have proved or disproved this.

The measurements of diameter of new roots reaches the maximum much later than those in perennial ryegrass - 5th June, as opposed to 8th April. The weights show an increase with increase in numbers of new roots and branching.

TABLE XXXIV. Seasonal growth of new roots in short rotation ryegrass.

Date	No. new roots.	No. over 6" in length.	Extent of Branching.	No. tillers	No. new roots/ tiller.	Weight (gms)	Diameter largest new root. (m.m.)
19/11/46	-	-	-	328	-	-	-
10/12/46	-	-	-	268	-	-	-
24/1/47	6	-	-	231	.03	-	.3
7/2/47	14	-	-	281	.05	-	.4
28/2/47	71	-	-	463	.2	.3	.4
18/3/47	95	-	-	299	.3	.5	.6
8/4/47	156	2	1 st order	365	.4	.9	.5
30/4/47	96	13	1 "	262	.4	.7	.6
17/5/47	158	9	1 "	414	.4	1.6	.6
5/6/47	98	35	2 nd "	348	.3	1.2	.8
27/6/47	182	108	2 "	724	.3	4.8	.8
15/7/47	153	122	2 "	476	.3	6.6	.8
6/8/47	148	81	3 rd "	327	.5	8.7	.9
31/8/47	257	119	3 "	317	.8		

(iv) The survival of the adventitious roots.

Table XXV shows the number of old roots per tiller surviving at each lifting. At the last lifting it is apparent that about one-third of the old roots have survived.

TABLE XXXV. Survival of old roots of short rotation ryegrass.

Lifting No.	Date	No. surviving old roots.	No. tillers	No. roots / tiller.
1	19/11/46	911	328	2.7
2	10/12/46	766	268	2.8
3	24/1/47	628	231	2.7
4	7/2/47	464	281	1.7
5	28/2/47	720	463	1.6
6	18/3/47	494	299	1.6
7	8/4/47	710	365	1.9
8	30/4/47	429	262	1.6
9	17/5/47	675	414	1.6
10	5/6/47	366	348	1.1
11	27/6/47	576	724	.8
12	15/7/47	459	476	1.0
13	6/8/47	212	327	.7
14	31/8/47	280	317	.9

(v) Root hair development.

Root hair development in both old and new roots of short rotation are similar as regards positions of concentration, and actual concentration in the later stages of the trial. At the 11th lifting (June 27) it was noted that the new roots of both perennial and short rotation ryegrass showed such similarity as regards hair development that there was no distinguishing between them.

Decrease in concentration of root hairs on old roots was noted at the same time as in perennial ryegrass (8th April), but there was little development on the few new roots observed in January (lifting 3). At the 6th lifting (March 18), development on the new roots was comparable to that in perennial ryegrass.

(vi) Other observations.

Table XXXVI tabulates data to which little significance could be attached as far as seasonal growth of roots is concerned.

TABLE XXXVI. Measurements of old adventitious roots in short rotation ryegrass.

Lifting No.	Date	Length of root system. (Inches)	Extent of Branching.	Diam. largest white root. (m.m.)	Diam. of sloughed roots. (m.m.)	*Weight of old root system. (gms).
1	19/11/46	18	3 rd order	.6	-	48.1
2	10/12/46	21	3 "	.6	-	49.6
3	24/1/47	20	3 "	.7	-	21.6 (2)
4	7/2/47	18	4 "	.7	-	36.5 (2)
5	28/2/47	19	4 "	.7	-	30.0
6	18/3/47	22	4 "	.7	.4	31.1 (1)
7	8/4/47	21	4 "	.8	.4	20.3 (2)
8	30/4/47	22	4 "	.8	.3	15.6 (2)
9	17/5/47	20	3 "	.7	.4	36.2
10	5/6/47	19	3 "	.9	.3	33.6 (2)
11	27/6/47	17	4 "	.7	.3	38.3
12	15/7/47	18	4 "	.8	.4	34.7
13	6/8/47	18	3 "	.9	.4	22.9 (1)
14	31/8/47	18	3 "			

* Weight of roots of 3 plants except where no. of plants weights is indicated in brackets.

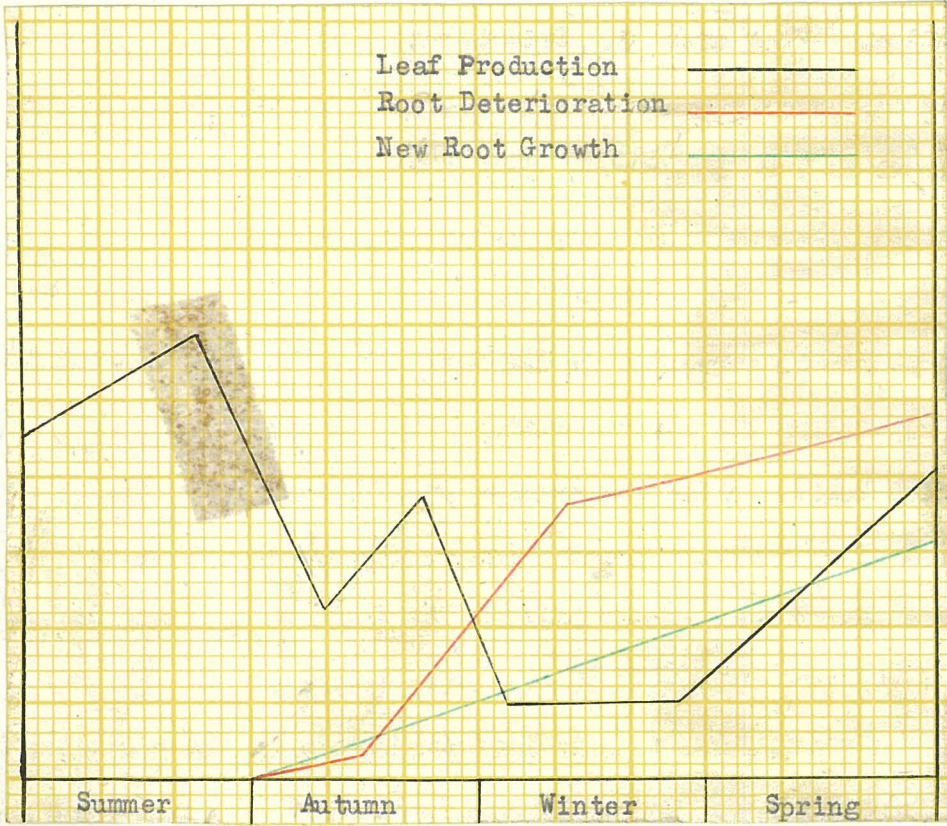


Figure 20. A general illustration of the relationship of seasonal leaf production with root deterioration and new root growth in the pasture plants studied.

SECTION V. DISCUSSION OF RESULTS.

(i) General implications of results and the limitations of their interpretation.

From the data that have been presented in the preceding section, two features of the seasonal root growth stand out as being of importance in considering the seasonal leaf growth and persistency of those pasture plants studied. They are: 1. Deterioration of the old root system (primary in clovers; secondary or adventitious in the grasses) after one year of growth in late summer or autumn. 2. New growth of roots which begins in most cases at nearly the same time as deterioration of the old roots.

The graphs presented in detailing these results in each species or strain all follow the general pattern that is shown in fig. 20. Deterioration begins in the late summer and increases with the approach of the flush of autumn leaf growth, continuing as production falls for the winter. The number of new roots produced increases from summer. From this a general picture of the seasonal growth of the plant as a whole may be deduced. With the fall in leaf production in the summer, (root reserves are called on to maintain production in the autumn), resulting in a rapid deterioration of the roots. This continues in the winter until a maximum deterioration is reached, the lowered production in this season being attributed in part to the loss in absorptive root area. New rooting is increasing in the meantime until spring, when leaf production is made possible by the absorptive action of the new roots in the soil. The earliness of spring growth would depend on the amount of development of these new roots.

The persistency of any species would depend, then, upon the combined effects of the extent of deterioration or the amount of survival of the old roots, and the extent of replacement or new rooting. The differences between various species and strains in regard to their persistency of growth may be correlated to the seasonal behaviour of their root systems by reference to data compiled under the headings of the seasonal growth of new roots, and survival of old roots. With the approach of the second year of growth, new roots are formed, which increase in number through the second winter. Through the season, these roots develop in respect to diameter,

length and extent of branching. If sufficient roots are formed to replace those lost by deterioration, and if they are sufficiently developed to function, the plants survive showing the quality of persistence. In the non-persistent species, new root development is insufficient to replace those roots lost.

Construction of this general picture of seasonal pasture plant growth is presented with some reservations. Although the data for deterioration of the old roots and new root growth shows some relationship to the seasonal leaf growth and persistency in all species, the explanation of it cannot be emphasized, because of the limitations imposed by the method of investigation that was adopted, and nature of root material that renders it difficult to subject the seasonal traits exhibited to measurement. Before substantiating the general outline that has been given of the seasonal growth of pasture plants by more detailed reference to the data obtained in this investigation, it may be expedient to point out the limitations to which any interpretation of this data is subject.

1. The explanation of deterioration is not proven. Whether storage of nutrients exists in the adventitious roots of grasses is uncertain, although the primary root system in clovers, from sections made in April 1947, showed some starch storage (Appendix IX). It is possible that nutrients are stored in grass roots in the form of complex sugars. More detailed chemical investigation is necessary to confirm this. An alternative explanation of the cause of deterioration may be merely the ageing of roots. Stoddart (1935) seemed to subscribe to this view.
2. By taking only the roots in the top 12 inches of soil, it was not possible to observe any changes in the roots at a lower level. Thus any seasonal changes which occurred were not recorded.
3. The deterioration of the primary root system in clovers ended with the rotting away of the whole system, but it was not possible to ascertain directly whether secondary roots in the grasses which showed cortex sloughing were dead or alive, or whether there was any rotting of the roots, because of their fineness. This has been a problem encountered by overseas workers. Stuckey (1941) traced the roots to the tips and from sectioning recognised live roots from mitotic division figures of cell nuclei there, while Weaver and Zink (1946) using a root banding technique, were satisfied that roots were alive from their survival and condition. In this investig-

ation, deterioration in grass roots was measured as a percentage of old roots affected by cortex sloughing, and thus gave no indication of whether the roots thus affected were functional or not. It is most likely, in the light of Stuckey's findings in cocksfoot, that many roots affected by cortex sloughing may still be able to absorb plant nutrients in the soil at levels lower than 12 inches, where the cortex is probably intact.

4. The attempt to find the extent of replacement of the old root system by new root growth in grasses was not wholly successful. This was done by taking the number of roots that survived at each lifting, and the number of roots that were formed as numbers per tiller. It was thought that from these measurements, two deductions could be made: (a) The proportion of the old root system that died could be determined, as shown by the number of old roots per tiller at the first lifting and the last. (b) The amount of replacement of these roots by new growth could be found.

The factor which rather modified the importance of these results was the nature of the seasonal growth of tillers. While at each lifting of plants, the number of tillers were counted in each grass species, no account was taken of the change in tiller numbers in individual plants. This was important, in that, taking a single plant with a constant root number, an increase in tiller numbers automatically decreases the roots per tiller ratio. Similarly a dying off of tillers would increase it. That there were new tillers formed during the period of the trial was obvious, but whether they replaced tillers that had died off, was problematical. In most of the grasses there appeared to be a tendency for the plant to replace roots lost by new growth, but in the light of the above criticism, it is difficult to know how accurate a representation of the facts that this is. A study of tillering habit in the various grasses would clarify this situation.

In the clovers, no such problem was encountered since it was obvious that the primary root system was replaced by the secondary or adventitious system. After the rotting away of the primary root system and the lack of connection between tillers resulting, these apparently continued existence as separate plants.

5. The trial did not extend over a full year, concluding at the end of August, 1947, before the flush of spring growth, and therefore the situation regarding root changes in the spring cannot be reported.

6. The necessity for using seed to produce clover plants for the trial introduced genetic variation as a limiting factor to the interpretation of results. This is demonstrated by graphs (figs. 5, 6, 9 and 10) for deterioration of primary root systems and new growth of roots in the clovers. They are all irregular, so that while a tendency for increase of both factors of seasonal root growth is obvious, the accuracy of the individual points on the curves is questionable. A greater number of plants of each species or strain per lifting may have obviated this difficulty.

Taking clones from single plants of grasses to obtain material for root observation virtually dispensed with any genetic differences between individual plants of the same species or strain; but due to either the failure to select uniform tillers, or to small soil differences in the individual pipes in which they were planted, tiller numbers and root numbers per plant differed so markedly between plants, that roots per tiller was taken for comparative measurements. Thus there was a lack of uniformity in the grass material, even with the precautions taken.

Weaver and Zink (1946) in their studies on seasonal root growth of some prairie grass species made their seasonal observations of root survival using a technique of banding individual roots, and making periodic inspections of the roots, after each of which soil round the roots was replaced. Thus the plant inspected was not destroyed, as was the case after each observation in this study, and the difficulty arising from variation in root behaviour between individual plants due to genetic or environmental conditions was eliminated. However it would be difficult to apply this technique to the species studied in this present trial, since the root parts involved are much finer than those of the prairie and range species, and would be difficult to mark by banding. Also the inspection of roots and replacing of soil afterwards would be difficult.

7. Under such treatment as the plants received in this trial, where competition from weeds or other grasses was excluded, the results may differ widely from those which, if it were possible, would be obtained under normal pasture conditions. Particularly so in the annual plants whose persistency may be exaggerated under these conditions. Western Wolths, for example, persisted until June 1947 - 14 months, and the plant from which tillers for planting originated was over one year old.

8. In comparing seasonal deterioration and new growth of roots with leaf

growth in the 'annual' plants production curves were used of first year pasture yield figures. This does not give a fair comparison since all data for deterioration and new growth of roots was made when the plants were in the second year of growth. This was the case in Italian ryegrass, broad red clover and Montgomery red clover. In all species, a better comparison between seasonal production and root behaviour may have been obtained if figures for leaf growth had been taken from the plants in the plots by weighing of the foliage which was trimmed off throughout the trial.

9. Due to the nature of the root material, the possibility of errors in estimation of both deterioration and new growth of roots in grasses and clovers has to be allowed. In the clovers, it was not possible to measure deterioration objectively, but by using a system of allotting of points or grades to different intensities of deterioration. Thus the likelihood of error of a subjective nature is introduced, especially in the maintenance of standards of these grades at successive liftings of plants of a species or strain, after the lapse of three weeks between each. The new rooting in clovers was assessed directly by counting the numbers of new roots arising from each tiller or stolon. This more objective method of measurement was still prone to error, since, although the number of tillers could be accurately counted by cutting the primary root system away from the remainder of the plant at the point of attachment, the separation of the stolons (especially in the white clovers) to count the roots on each was difficult.

In the grasses there was again the problem of finding some basis for measurement. For comparison with seasonal leaf production, deterioration was measured as a percentage of total old surviving roots, and new root growth as a percentage of total roots. It can be seen that deterioration and new growth are not directly comparable as measured on these bases. Thus to study the replacement of old by new roots, these were brought to a common basis of measurement - roots per tiller. Again the fineness of the root material introduced the possibility of error in counting of the roots. The number of roots per plant at any observation is obviously an objective reality, but the execution of such a measurement is prone to error of a subjective nature. Also the error may not be a constant proportion at different liftings of plants of the same species or strain.

Root hair development proved the most difficult to measure. Statements regarding development are presented without substantiating figures. Attempts to make counts microscopically with the aid of a micrometer gauge in the eyepiece of the microscope were not successful. Root hairs were so concentrated in some parts of the roots that counts of numbers per 2 m.m., could not be repeated within 10 on the same part of the root a few minutes after the first count was made. A standardised technique for counting the root hairs was not adopted, so that real proof of the statements made in regard to seasonal change in numbers cannot be claimed.

Other measurements such as weight of old roots throughout the period of the trial were expected to show a decrease due to deterioration. That this was not the case was probably due to difficulty in washing away all the soil from the roots, or the influence of small differences in the soil of the plot - texture, nutrients available, etc. The lifting of a greater number of plants at each observation would have allowed some scope to show statistical differences between average weights of those groups of plants at different observations.

With these limitations outlined, the next section presents the attempt to render the substantiation of the general picture of seasonal growth of pasture plants that was expressed in the beginning of this discussion, by the use of the data obtained in this trial on seasonal root behaviour of the ten different pasture species or types that were tested.

(11) INTERPRETATION OF RESULTS.

The features of seasonal root behaviour which are discussed in connection with seasonal leaf production and persistency of growth in the species or strains studied are the deterioration of the original root system (primary in clovers; secondary in grasses), the number of adventitious roots formed, and the development of the individual new roots. These all appeared to show some relationship to leaf production and persistency in the plants studied, but this does not preclude the possibility that other factors in root growth may show some connection. Due to lack of measurement devices, as, for example, in the case of root hair development, and deficiencies of method of investigation outlined previously, which influence such factors as root weights, diameters, etc, these cannot be related to the seasonal leaf growth of the plants involved, since they show no

obvious seasonal trends.

THE RED CLOVERS:

Since no production figures for second year growth were available in Montgomery or broad red clovers the comparisons between leaf production for the first year of growth and root behaviour in the second year of growth in both types (figs. 6 and 5) cannot be regarded as accurate. The only fact that can be indicated is that deterioration and new growth of roots assume somewhat similar positions relative to seasonal production of leaf (taking first year production figures) to those in the 'perennial' grasses and clovers. Deterioration of the primary root system begins in the late summer, there being a marked intensification in the autumn at the time of the flush of top growth, then a steady continuation of deterioration as production falls for the winter. Adventitious rooting from the tillers begins at the same time as deterioration of the primary root system, and shows a fairly uniform increase throughout the autumn and winter. Crown rooting increased until deterioration was at an advanced stage, when there was a decrease. The function of the 'crown' roots is difficult to ascertain. Whatever their purpose, they appear to function for a short period only, probably in place of the primary root system which is deteriorating, when the plant cannot rely on the under-developed adventitious roots that are being formed on the stems.

Persistency in the red clovers differs somewhat from the general description presented in the first section of this discussion. The trend in deterioration of the primary root system indicates that there is no survival after the second season of growth, so that whether the plant survives the second winter depends solely on the development of new roots. The present trial on red clovers was not continued long enough to obtain maximum deterioration, i.e. complete disintegration of the primary root system, that was noted in both white clovers, except in one observation in broad red clover (July, 1947). However, there was a general tendency for intensification of deterioration and it was apparent that were it possible to continue the trial, disintegration of the tap roots on all plants would have been observed, and had the plants survived, this would have been due to the action of the new adventitious root system in the soil. As Saxby (1945) states, the Montgomery strain of red clover is

more permanent than the broad red. An explanation for this on the basis of seasonal root behaviour is that although deterioration of the primary root system is observed in Montgomery red clover over a month before it is in broad red, it appears to proceed at a slower rate, so that in August, the majority of plants may still have been utilising reserves stored in the tap root. Allied to this is the fact that development of adventitious roots per tiller was much greater in Montgomery red clover than in broad red. At the last observation in August, 1947, there were 24 adventitious roots per tiller in Montgomery red clover as against 18 per tiller in broad red, as tables I and IV show. Tables II and V show that at the latter stages of the trial, adventitious roots of the Montgomery strain are more developed in terms of length and extent of branching. Thus it would seem that the persistency of the primary root system and the more rapid growth and development of the adventitious roots from the tillers can account for the greater power of survival of Montgomery red clover over the broad red strain.

THE WHITE CLOVERS:

The seasonal leaf production is compared with primary root deterioration and new root growth in both ordinary N.Z. white clover and No. 1 N.Z. pedigree white clover in figures 9 and 10 respectively. It can be seen that in both types of white clover the seasonal trend in production is similar. There is a drop in leaf growth from December, until in February there is a late summer-early autumn flush in growth, and from then on a fall over the winter. The poor white strain shows a lower production over all seasons in the year, and this is especially noticeable in the autumn and winter. Primary root deterioration was observed in both strains in January, 1947, and its increase showed the typical inverse relationship with the fall in production after the autumn flush of leaf growth. Crown root numbers were at their maximum in the autumn, and they may have functioned in a temporary capacity in support of the deteriorating primary root system. Deterioration appears to show a slower rate of intensification in No. 1 white clover than in the ordinary type, but the problem arising from the variability inherent in this seed, which has been previously discussed, makes the interpretation

of the data difficult, especially in attempting to compare the two white clover types with respect to their autumnal leaf growth differences. The low winter growth in the poor white clover must be connected with the total collapse of the primary root system, the plants surviving solely on the adventitious root system, which has in the meantime developed. The higher winter growth in No. 1 white clover may be attributable then, to the longer survival of the primary root system, and the greater numbers of adventitious roots that have formed.

The persistency of No. 1 white clover is superior to that in the ordinary white clover. From table VII it can be seen that the number of new roots per stolon formed is uniformly high (50-70/stolon) at the latter six liftings of No. 1 white clover, while in the corresponding liftings of the poor strain, the number varies between 20 and 70. It is obvious that the number of adventitious roots that are formed has some bearing on the survival of the plant. In poor white clover, at one lifting, 74 adventitious roots per tiller were counted, a number that was never observed in observations on the new roots of No. 1 white clover. This count was never repeated in subsequent liftings of poor white clover. This brings forward an observation regarding the relative qualities of the two types of clovers. From observations of the root behaviour of the two types, particularly the new growth of roots, it appears that No. 1 white clover exhibits much more uniform tendencies throughout the season. The seasonal production of new roots show a more constant trend, and from tables VIII and XI, the growth of the new roots formed show much more consistent tendencies of increase in regard to length and diameters. It would therefore seem that in No. 1 white clovers its qualities lie in the uniformity of the seed, which is expressed by the more stable root behaviour that plants exhibited in this trial. In the poor strain, the extreme variation between individual plants shows the heterogeneous nature of the seed. Not only was this evident in root behaviour, but also in top-growth. Some plants appeared to be growing as well as, or better than No. 1 white clover, but many were very much inferior. This was not evident from tiller numbers as shown in tables IX and XII, but would have been reflected by actual measurements of leaf growth in terms of weight, sizes of leaves, etc.

COCKSFOOT.

The seasonal leaf production of C.23 cocksfoot is graphed in fig.13. Summer production begins to fall in January; there is a slight rise in the autumn then a fall as winter approaches in May. The first sign of deterioration of the root system was observed in January and this progressed until late April, at the time of the autumn flush, deterioration reached 100% of the total number of old roots. After this there was a decline in leaf growth during the winter months. New root growth showed increase through the period of the trial. Spring growth is reputed to be early but not rapid in this strain of cocksfoot, and the data of the survival of the old root system, seasonal growth of new roots and tillering during the winter, rather supports this. The original number of roots per tiller was 5 - 75 (table XIX) before any signs of deterioration were evident. At the end of the trial, the number of surviving roots was 1.6 per tiller. Now the 'replacement' or new roots at the same time was only 1.0/tiller (table XVIII), so that the total number of roots per tiller is in the vicinity of 3. Until there is a greater number of new roots either to replace those roots which have deteriorated, or to support new tillers that have been formed, leaf growth will be slow in the spring. Since C.23 cocksfoot is known to be a fairly persistent strain under favourable management, it is probable that growth and development of new roots continues well into the spring. The number of tillers that are formed over the winter (table XIX) enables an early spring growth which is not rapid due to the lack of development in the new root system (table XVIII).

There is nothing in the root data, which indicates that Danish cocksfoot is short-lived. The lower production is possibly indicated by the trends in seasonal deterioration of the roots. Deterioration was quite evident in the first observation (Nov.1946) and increased until in March, 100% of the total number of old roots were affected by sloughing of the cortex. This meant the stage where absorption area of the old roots were at a minimum was reached nearly two months earlier than in C.23. Earlier summer growth may be explained from the survival of old roots - 4/tiller approx. (table XV) and the growth of new roots - 2-3/tiller (table XIV), at the end of the trial, which together approximate the original number of old roots per tiller, 6-9 as indicated in table XV. The replace-

ment of the old roots by new roots was earlier in Danish cocksfoot than in the C.23 strain and thus accounts for the earlier leaf growth.

The higher leaf production of C.23 cocksfoot in winter is probably due to the fact that new tillers were produced throughout the winter.

Comparing tables XIV and XVIII, it is evident that there is little tillering in Danish cocksfoot over the winter, so that growth activity in this plant over this period is confined to the underground parts - the development of new roots.

New rooting was observed at the first observation in November 1946, so that subsequent growth and development of the new roots was in advance of that in C.23 at any particular time (c.f. Tables XIV and XVIII). This supports the replacement data in explaining the relative earliness and rapidity of summer growth in the Danish strain.

THE RYEGRASSES.

Italian ryegrass and Western Wolths represents the 'annual' type of ryegrass in this trial. As has been pointed out, the results obtained on root behaviour cannot actually be compared with seasonal leaf production figures, since those plants observed in the trial were two-year plants. The data does, however, show some explanation for the differences between length of life, or persistency of Italian ryegrass and Western Wolths and between Italian and the more permanent perennial and short rotation ryegrasses.

Deterioration of the old roots in Italian ryegrass was not observed until early February. After this month there was a sharp rise in the amount of deterioration until late March 60% of the total number of old roots was observed to show sloughing of the cortex. Thereafter there was a fairly steady increase. New root growth was fairly steady from February onwards as indicated by fig. XIV, and it would seem from this that root replacement was fairly high. In examining the data of new root growth (table XXII) and old root survival (table XXIII) it is found that the number of new roots per tiller at the last observation was 1.3, and the number of old roots per tiller surviving was 1.1. This gave a total number of roots per tiller at the last lifting of 2.4 approx. while the number of roots per tiller at the initial observations before the onset of root deterioration or

new growth was in the vicinity of 3.8 - 3.9. This meant, then, that at the end of August, the number of roots per tiller was about 60% of the same measurement in the preceding November. However, the limitations of over-emphasising this are outlined in the first part of the present discussion.

In Western Wolths, deterioration as sloughing of the cortex was not evident until March, and as a percentage of total old roots was relatively small without much increase from April till June. The number of old roots per tiller showed a great decrease from February on indicating either the loss of the original roots, or an increase in tillering. It seemed likely from table XXVII that the former was mainly the explanation although there was a greater number of tillers on the last plants observed than previous ones. At the last lifting before the death of the remaining Western Wolths plants in June, the number of old roots surviving was .5 per tiller, and the number of new roots was .3 per tiller, totalling .8 roots per tiller, or 23% of the number of old roots (4.5/tiller) originally observed (table XXVII). It would therefore seem as though the root system was not developed sufficiently to meet the demands of the plant in surviving the second winter.

In perennial ryegrass seasonal leaf production follows the trends typified by the production line in fig.20. After the maximum production period of up to January, there is a summer slump, then autumn recovery March to April, followed by the low production winter period. Root deterioration begins in late summer and there is a sharp intensification at the time of maximum autumn leaf growth. Thereafter there is a steady increase in the percentage deterioration. New root growth was first observed in January, and showed a fairly steady increase until in August 41% of the total number of roots were new. To obtain a more detailed picture of the root changes in numerical terms the number of roots per tiller at the first observations before the onset of deterioration and new rooting was observed, was 2.3 - 2.8; the number of roots surviving in August, 1.0 per tiller (table XXXI) and the number of new roots per tiller at this time .9 (table XXX). Thus the total number of roots per tiller in August was 1.9, or about 75% of the original number. Thus it would seem that the replacement of old roots which have been eliminated is rapid and makes the spring leaf growth that is characteristic of perennial ryegrass.

Production of leaf in short rotation ryegrass followed similar

trends to those in perennial ryegrass. From fig.19, it may be observed that the summer slump in production was not as severe as that in perennial ryegrass, but the autumn flush of growth did not reach the proportions of that in the latter. The difference between the extent of the summer drop in production in perennial and short rotation ryegrasses cannot be related to any differences in seasonal root behaviour; but root deterioration in short rotation ryegrass which was observed to begin at the same time (early February) as that in perennial ryegrass shows a much slower intensification, indicating that there may be a higher rate of utilisation of reserves in perennial ryegrass to obtain a higher leaf production in the autumn. Winter production in short rotation ryegrass is higher than in perennial, indicating a more even spread of utilisation of reserves in the former.

New root growth in short rotation rather parallels that observed in perennial ryegrass, being first observed in January, and showing a steady increase until in August new roots numbered 48% of the total roots. The spring leaf growth of short rotation is stated by Corkhill (1945) to be earlier than in perennial ryegrass but the behaviour of the root system of short rotation ryegrass in terms of survival of the original root system and new roots did not explain this. The number of roots per tiller at the first observation (Nov.1946) before the advent of root deterioration in the form of cortex sloughing or new rooting was fairly constant at 2.7 (table XXXV). The surviving roots per tiller at the last observation (Aug.1947) numbered .9, and the number of new roots at that time was .8 per tiller (tables XXXIV and XXXV). Thus the number of roots per tiller in August was 1.7 or about 65% of the original number. In comparing the seasonal growth of the new roots of both grasses (tables XXX and XXXIV), development of the new roots was similar in respect of proportion of roots over 6" in length, extent of branching, and diameters, i.e. the new roots of both perennial and short rotation ryegrasses were at similar stages of development in August. Thus it seemed that perennial ryegrass with its greater number of new roots per tiller, behaved paradoxically in its comparative lateness of spring leaf growth. However it was stressed at the beginning of this discussion that there are many factors limiting the explanation of this data. It is opportune

to apply the possible implications of some of these limitations to the present situation, which has arisen in attempting to reconcile root behaviour with earliness in spring leaf growth of perennial and short rotation ryegrasses.

1. The trial did not extend into the spring. The situation regarding the number of roots per tiller in either ryegrasses or both may have changed since the last observation made in August.
2. The nature of deterioration in the grasses is fairly clear, but the inherent differences between ryegrass species in such factors of deterioration as loss of roots are not known. The complicating factors of tillering and dying off of old tillers that are not measured in this trial make the significance of measurements of numbers of roots on a per tiller basis questionable. Thus in this example of earliness of spring leaf growth in perennial and short rotation ryegrasses, it is possible that unknown factors may have influenced the accuracy of the measurements. On the other hand, the same chance must be allowed in those cases where the root behaviour does correspond to seasonal top growth, as in the two types of cocksfoot.
3. The design of the experiment allowing the observation of the root systems of three plants (at a maximum) only at each lifting did not permit any statistical treatment of data. In perennial ryegrass, the numbers of roots per tiller surviving (table XXXI) at the first four liftings were 2.5, 2.3, 2.3, 2.8. This was before any cortex sloughing was observed. These figures may have approximated one another were more plants observed at each lifting, and the results obtained statistically examined.

SECTION VI.CONCLUSION.

It cannot be claimed that the objects of this investigation have been fully attained. Firstly on setting down the seasonal changes in the root systems of those species and strains studied, only the nature of the two, namely deterioration of the original root system (primary in the clovers; secondary in grasses), and growth of new roots can be said to have been satisfactorily determined.

The superficial relationships of these two root changes to the seasonal cycle of leaf production were able to be made, but the implications of these relationships could only be put forward with many reservations. Not only were there limitations due to the planning of the experiment and the lack of means of objective measurement of the root changes, but also the lack of knowledge of the biochemical aspects of nutrient storage and utilisation in grass and clover roots, which prevents the formation of an accurate picture of seasonal pasture plant growth. Donald (1941) makes an unauthenticated statement, "The seasonal cycle of production is intimately related to the physiology of the plant. The burst of growth preceding flowering, and the transference of reserves to the crown and root occur at different seasons in different species". Without seasonal chemical determinations of 'reserves' in both roots and foliage of different species, such a conclusion is difficult to accept. If transference of reserves is correlated in some way with root deterioration, the present study indicates that this transference occurs at approximately the same season (late summer - autumn) in the *Trifolium*, *Dactylis* and *Lolium* species and strains investigated.

While Stuckey's classification (1941) of grass roots into 'annual' and 'perennial' types cannot be confirmed owing to the inopportune cessation of the present study, it is apparent that general statements sometimes expressed in the literature such as Levy's (1943), "For each growing season a new root-system is developed", cannot be made in reference to grasses. While this statement cannot be entirely negated in reference to clovers, nor can it be taken as fact, since no work has been conducted investigating the seasonal behaviour of the roots, as far as is known. This investigation showed that in some clovers (notably the red clovers) the primary root system

survived well into the second year, but the subsequent behaviour of the secondary roots formed could not be observed, and it is possible that these roots may assume the 'annual' habit.

To obtain a more positive and complete portrayal of seasonal root growth in relation to seasonal leaf production, it is apparent that three factors, which were not considered in this investigation, must be taken into account.

(a) In planning the experiment, more plants of each species or strain should be grown, so that a greater number of each can be observed at intervals than was the case in this experiment. The observations should extend over a period of more than one year, to enable complete cycle of root growth to be observed. It seems advisable to take yields of the actual plants during the trial to gain a closer relationship between root behaviour and top growth.

(b) A greater familiarity with the root material to be handled would facilitate the setting up of objective standards by which to measure root changes. This, with statistical treatment of data from a greater number of plants, would give more conclusive evidence of correlations between deterioration, new growth of roots and seasonal leaf production, as well as enabling more objective observations of such considerations as root hair development which may have had some bearing on the question.

(c) Without a biochemical study of the storage and transference of reserves (if such exist) at the different seasons, it is difficult to explain the relationships of seasonal leaf growth to deterioration and new growth of roots.

It can be seen that the relating of seasonal root changes to leaf production in pasture plants involves far wider issues than were first envisaged. Actually to attain this object means to study the growth of the entire plant, and this is inseparable from many physiological and biochemical considerations which were out of the range of this investigation.

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APPENDIX I.PRODUCTION FIGURES OF BROAD RED CLOVER.

Result of trials conducted by the Plant Research Bureau; sown 8/11/45.

Period between cuts.	Days	D.M. lbs. per acre.	D.M. lbs/ acre. 1 day.	20 day Periods.	D.M. lbs/ acre in 20 day periods.
4/1/46 - 24/1/46	20	642	32	4/1/46 - 24/1/46	642
24/1/46 - 9/2/46	16	642	30	24/1/46 - 13/2/46	794
9/2/46 - 25/3/46	44	1674	38	13/2/46 - 5/3/46	760
25/3/46 - 29/5/46	65	623	10	5/3/46 - 25/3/46	760
29/5/46 - 10/9/46	104	848	8	25/3/46 - 14/4/46	200
				14/4/46 - 4/5/46	200
				4/5/46 - 24/5/46	190
				24/5/46 - 13/6/46	160
				13/6/46 - 2/7/46	160
				2/7/46 - 22/7/46	160
				22/7/46 - 11/8/46	160
				11/8/46 - 31/8/46	192
10/9/46 - 7/10/46	27	1096	41	31/8/46 - 19/9/46	820
7/10/46 - 30/10/46	23	1039	41	19/9/46 - 9/10/46	820
				9/10/46 - 29/10/46	1007
30/10/46 - 6/12/46	27	2158	58	29/10/46 - 18/11/46	1160
6/12/46 - 3/1/47	28	1277	46	18/11/46 - 8/12/46	992
				8/12/46 - 28/12/46	782
3/1/47 - 30/1/47	27	632	23	28/12/46 - 17/1/47	460

APPENDIX II.

PRODUCTION FIGURES OF MONTGOMERY RED CLOVER.

Result of trials conducted by the Plant Research Bureau; sown 8/11/45.

Period between cuts.	Days	D.M. lbs. per acre.	D.M. lbs/ acre 1 day.	20 day periods	D.M.lbs/ acre in 20 day periods.
4/1/46 - 24/1/46	20	505	25	4/1/46 - 24/1/46	505
24/1/46 - 9/2/46	16	709	44	24/1/46 - 13/2/46	885
9/2/46 - 25/3/46	44	1372	31	13/2/46 - 5/3/46	620
25/3/46 - 29/5/46	65	560	9	5/3/46 - 25/3/46	620
29/5/46 - 10/9/46	104	190	2	25/3/46 - 14/4/46	180
				14/4/46 - 4/5/46	180
				4/5/46 - 24/5/46	180
				24/5/46 - 13/6/46	75
				13/6/46 - 2/7/46	40
				2/7/46 - 22/7/46	40
				22/7/46 - 11/8/46	40
				11/8/46 - 31/8/46	40
10/9/46 - 7/10/46	27	739	27	31/8/46 - 19/9/46	315
7/10/46 - 30/10/46	23	1109	48	19/9/46 - 9/10/46	645
				9/10/46 - 29/10/46	849
30/10/46 - 6/12/46	27	1380	37	29/10/46 - 18/11/46	740
6/12/46 - 3/1/47	28	1634	58	18/11/46 - 8/12/46	824
				8/12/46 - 28/12/46	1160
3/1/47 - 30/1/47	27	626	23	28/12/46 - 17/1/47	600

APPENDIX III.PRODUCTION FIGURES OF ORDINARY N.Z. WHITE CLOVER.

Results of trials conducted by P.R.B., sown 25/8/46.

Period between cuts	Days	D.M.lbs. / acre.	D.M.lbs. /acre /day.	Period between liftings.	Days	D.M.lbs./ acre/period between liftings.
21/5/46 - 8/7/46	48	33				
8/7/46 - 6/9/46	60	500				
6/9/46 - 3/10/46	27	644	24			
3/10/46 - 29/10/46	26	952	37	27/10/46 - 15/11/46	20	1190
29/10/46 - 10/12/46	42	2585	62	15/11/46 - 6/12/46	21	1302
10/12/46 - 10/1/47	31	1598	52	6/12/46 -	21	1132
10/1/47 - 31/1/47	21	672	32	- 17/1/47	21	752
31/1/47 - 17/2/47	17	994	58	17/1/47 - 4/2/47	18	680
17/2/47 - 17/3/47	28	505	18	4/2/47 - 25/2/47	21	898
17/3/47 - 28/4/47	42	472	11	25/2/47 - 15/3/47	18	324
28/4/47 - 29/7/46	92	172	2	15/3/47 - 5/4/47	21	245
				5/4/47 - 26/4/47	21	231
				26/4/47 - 14/5/47	18	54
				14/5/47 - 4/6/47	21	42
				4/6/47 - 24/6/47	20	40
				24/6/47 - 13/7/47	19	38
29/7/47 - 8/9/47	41	407	10	13/7/47 - 4/8/47	22	92
				4/8/47 - 30/8/47	26	260

APPENDIX IV.PRODUCTION FIGURES FOR NO.1 PEDIGREE N.Z. WHITE CLOVER.

Result of trials conducted by P.R.B., sown 25/3/46.

Period between cuts	Days	D.M.lbs./acre.	D.M.lbs./acre/day.	Period between liftings.	Days	D.M.lbs/acre/lifting period.
21/5/46 - 8/7/46	48	136				
8/7/46 - 6/9/46	60	1159				
6/9/46 - 3/10/46	27	773	29			
3/10/46 - 29/10/46	26	1238	48	27/10/46 - 15/11/46	20	
29/10/46 - 10/12/46	42	2572	61	15/11/46 - 6/12/46	21	1281
10/12/46 - 10/1/47	31	1433	46	6/12/46 -	21	1426
10/1/47 - 31/1/47	21	909	43	- 17/1/47	21	915
31/1/47 - 17/2/47	17	1292	76	17/1/47 - 4/2/47	18	906
17/2/47 - 17/3/47	28	953	34	4/2/47 - 25/2/47	21	1260
17/3/47 - 28/4/47	42	706	17	25/2/47 - 15/3/47	18	612
28/4/47 - 29/7/47	92	523	6	15/3/47 - 5/4/47	21	391
				5/4/47 - 26/4/47	21	357
				26/4/47 - 14/5/47	18	130
				14/5/47 - 4/6/47	21	126
				4/6/47 - 24/6/47	20	120
				24/6/47 - 13/7/47	19	114
29/7/47 - 8/9/47	41	666	16	13/7/47 - 4/8/47	22	192
				4/8/47 - 30/8/47	26	416

APPENDIX V.PRODUCTION FIGURES FOR C.23 COCKSFOOT.

Results of trials conducted by P.R.B. sown 1/11/45.

Period between cuts	Days	D.M.lbs /acre.	D.M.lbs. /acre /day	Period between liftings.	Days	D.M./acre in lifting periods.
26/3/46 - 26/4/46	31	432				
26/4/46 - 1/7/46	65	793				
1/7/46 - 23/8/46	53	377				
23/8/46 - 4/10/46	42	622	15			
4/10/46 - 31/10/46	27	339	13	31/10/46 - 19/11/46	20	602
31/10/46 - 3/12/46	33	1020	31	19/11/46 - 9/12/46	20	520
3/12/46 - 18/12/46	15	234	16	9/12/46 -	21	588
18/12/46 - 10/1/47	23	858	37	- 20/1/47	21	627
10/1/47 - 3/2/47	24	533	22	20/1/47 - 5/2/47	16	364
3/2/47 - 4/3/47	30	834	28	5/2/47 - 26/2/47	21	588
4/3/47 - 17/4/47	44	633	14	26/2/47 - 16/3/47	18	336
17/4/47 - 14/5/47	37	631	23	16/3/47 - 6/4/47	21	294
14/5/47 - 7/7/47	54	592	11	6/4/47 - 28/4/47	22	407
				28/4/47 - 15/5/47	17	379
				15/5/47 - 5/6/47	21	231
				5/6/47 - 24/6/47	19	209
7/7/47 - 28/7/47	21	258	12	24/6/47 - 14/7/47	20	227
28/7/47 - 17/9/47	51	1061	21	14/7/47 - 5/8/47	22	336
				5/8/47 - 31/8/47	26	546

APPENDIX VI.PRODUCTION FIGURES FOR ITALIAN RYEGRASS.

Result of trials conducted by P.R.B., sown 12/3/45.

Period between cuts	Days	D.M.lbs /acre.	D.M.lbs /acre /day.	20-day periods	D.M.lbs/acre in 20-day periods.
20/4/45 - 7/5/45	17	1049	62		
7/5/45 - 25/5/45	18	307	17	7/5/45 - 27/5/45	290
25/5/45 - 15/6/45	21	141	7	27/5/45 - 16/6/45	236
15/6/45 - 18/7/45	23	710	31	16/6/45 - 6/7/45	620
18/7/45 - 21/8/45	34	1059	31	6/7/45 - 26/7/45	620
21/8/45 - 17/9/45	27	657	24	26/7/45 - 15/8/45	571
				15/8/45 - 4/9/45	480
17/9/45 - 18/10/45	31	538	17	4/9/45 - 24/9/45	340
				24/9/45 - 14/10/45	736
18/10/45 - 1/11/45	14	861	61	14/10/45 - 3/11/45	1335
1/11/45 - 19/11/45	18	1240	69	3/11/45 - 23/11/45	1380
19/11/45 - 7/12/45	18	1220	69	23/11/45 - 13/12/45	754
7/12/45 - 21/12/45	14	557	40	13/12/45 - 2/1/46	922
21/12/45 - 7/1/46	17	800	47	2/1/46 - 22/1/46	836
7/1/46 - 21/1/46	14	646	46		
21/1/46 - 8/2/46	19	765	40		

APPENDIX VII.PRODUCTION FIGURES FOR PERENNIAL RYEGRASS.

Results of trials conducted by P.R.B. sown 4/4/46.

Period between cuts	Days	D.M.lbs. /acre.	D.M.lbs /acre /day.	Period between liftings.	Days	D.M.lbs.in lifting periods.
22/5/46 - 3/7/46	40	974				
3/7/46 - 23/8/46	51	472				
23/8/46 - 1/10/46	39	1521				
1/10/46 - 31/10/46	30	1195	40			
31/10/46 - 3/12/46	33	1162	38	19/11/46 - 10/12/46	21	945
3/12/46 - 18/12/46	15	893	59	10/12/46 -	22	1016
18/12/46 - 8/1/47	21	855	41	- 24/1/47	23	591
8/1/47 - 8/2/47	26	496	19	24/1/47 - 7/2/47	14	286
8/2/47 - 14/3/47	39	919	24	7/2/47 - 28/2/47	21	504
14/3/47 - 17/4/47	34	924	28	28/2/47 - 18/3/47	18	448
17/4/47 - 13/5/47	26	834	32	18/3/47 - 8/4/47	21	588
				8/4/47 - 30/7/47	22	668
13/5/47 - 7/7/47	55	728	13	30/4/47 - 17/5/47	17	468
				17/5/47 - 5/6/47	19	247
				5/6/47 - 27/6/47	22	286
7/7/47 - 28/7/47	21	274	13	27/6/47 - 15/7/47	18	274
28/7/47 - 4/9/47	38	412	11	15/7/47 - 6/8/47	22	266
				6/8/47 - 31/8/47	25	275

APPENDIX VIII.

PRODUCTION FIGURES FOR SHORT ROTATION RYEGRASS.

Results of trials conducted by P.R.B., sown 4/4/46.

Period between cuts.	Days	D.M.lbs. /acre.	D.M.lbs. /acre /day.	Period between liftings.	Days	D.M.lbs. /lift. per.
22/5/46 - 3/7/46	40	1171				
3/7/46 - 23/8/46	51	929				
23/8/46 - 1/10/46	39	1833				
1/10/46 - 31/10/46	30	1019	34			
31/10/46 - 3/12/46	33	1185	36	19/11/46 - 10/12/46	21	679
3/12/46 - 18/12/46	15	377	25	10/12/46 -	22	788
18/12/46 - 8/1/47	21	874	42	- 24/1/47	23	870
8/1/47 - 3/2/47	26	933	36	24/1/47 - 7/2/47	14	440
3/2/47 - 14/3/47	39	771	20	7/2/47 - 28/2/47	21	420
14/3/47 - 17/4/47	34	697	21	28/2/47 - 18/3/47	18	364
17/4/47 - 13/5/47	26	774	30	18/3/47 - 8/4/47	21	441
				8/4/47 - 30/4/47	22	579
13/5/47 - 7/7/47	55	656	12	30/4/47 - 17/5/47	17	438
				17/5/47 - 5/6/47	19	228
				5/6/47 - 27/6/47	22	264
7/7/47 - 28/7/47	21	290	14	27/6/47 - 15/7/47	18	232
28/7/47 - 4/9/47	38	347	9	15/7/47 - 6/8/47	22	263
				6/8/47 - 31/8/47	25	225

APPENDIX IX.DETECTION OF STARCH STORAGE IN ROOTS OF CLOVER AND GRASSES.

Results of tests by transverse sectioning of roots and iodine treatment of sections, April 17, 1946.

CLOVERS:

Species or Strain	Sections Tap Root.	Sections Branches of primary root system.	Sections Adventitious roots.
Montgomery red clover	+	+	-
Broad red clover	+	+	-
Ordinary N.Z. white clover	+	+	+
Pedigree N.Z. white clover	+	+	+

GRASSES:

Species or Strain	Sections Adventitious old roots.	Sections Adventitious new roots.
Danish cocksfoot	-	-
C.23 cocksfoot	-	-
Western Wolths	-	-
Italian ryegrass	-	-
Perennial ryegrass	-	-
Short rotation ryegrass	-	-