AN ABSTRACT OF THE THESIS OF

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Title Root Development of Certain Perennial Legumes as Influenced by Soil Types.

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Abstract Approved:
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Perennial legumes are the keystone of permanent agriculture. They are used extensively as hay, pastures, soiling crops, silage, green manure, cover crops, and seed crops, and are outstanding as soil builders.

In the Willamette Valley there are approximately 105,500 acres of perennial legumes under cultivation. This large acreage and the fact that no information is available on the reactions of perennial legume roots in this region justifies undertaking this study.

The objectives of this study were to determine: (1) what perennial legumes are best adapted to a given soil type, and (2) the characteristic root systems, and the extent and zone of greatest root activity as influenced by soil types.

The crops used in this study were: (1) Alsike clover, (2) White clover, (3) Ladino clover, (4) Strawberry clover, (5) Red clover, (6) Lotus (7) Sweetclover, and (8) Alfalfa.

The crops were seeded in Chehalis clay loam, Willamette clay, and Melbourne clay soil types. These soils were selected because of their outstanding importance and because they are representative of the three major soil groups in the Willamette Valley.

The seed bed preparation and rate of seeding were the same as those commonly practiced by good farmers in this region.

Three methods of root excavation were used in this study. They are the Iron Cylinder Method, Direct Tracing Method, and the Direct Washing Method. The latter method was developed from a suggestion made by G. R. Hyslop. This method consisted of washing the root systems from the face of a trench with a stream of water under low pressure. Care was taken to locate this trench to avoid destruction of any roots and was of such size to allow the worker to move about freely.

After excavation the roots were separated, thoroughly cleaned, fixed on a black lacquered plate, and photographed.

The porosity, mechanical analysis, and chemical analysis were determined at various depths for each soil type in which plants were studied.

Results of the study show:

(1) That perennial legumes studied can be classified into two general groups: (a) Deep feeders, namely, alfalfa, sweetclover, lotus, and red clover; and (b) Shallow feeders, namely, alsike, white, Ladino, and strawberry clover.

(2) Little difference was shown in the early root growth of the legumes in the different soils.

(3) The influence of soil types in the root systems is cumulative with age.

(4) The feeding zone of roots is controlled principally by moisture relationships. Such factors as available nutrients, structure, and organic matter appear to be of secondary importance in this experiment.

(5) Moderately compacted soils tend to produce finer textured root systems than more open porous soils.

(6) Tightly compacted zones, (tillage pans), appeared to cause a reduction in the number and spread of laterals and the taproot in penetrating it was reduced in size, flattened and at times contorted.

(7) At maturity root penetration was greater in open textured soils than in moderately compact soils.

(8) Availability of plant nutrients appeared to show some influence on root development earlier than did the physical factors of the soil.

(9) Bed rock prevented root penetration in the Melbourne Soil.

(10) Roots tended to follow small noncapillary pore spaces in their downward passage but failed to follow the larger noncapillary openings.

(11) Chehalis clay loam is the best soil type under observation for production of perennial legumes. Alfalfa and white sweetclover made fair growth in the Willamette clay soil type and may serve as a means to improve the subsoil conditions of this soil.

ROOT DEVELOPMENT OF CERTAIN PERENNIAL
LEGUMES AS INFLUENCED BY SOIL TYPE

by

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INTRODUCTION

Root investigations of the important agricultural plants have been seriously neglected. This situation is only natural because of the difficulties encountered in undertaking such studies. However, increased interest and information about the rooting habits of plants in the last 50 years indicates that difficulties in making these studies have been partially overcome, and that the importance of such knowledge is being recognized.

It cannot be stated that perennial legumes are the most important crop in agriculture, but agricultural history, down through the ages, proves definitely that they are the keystone upon which all permanent agriculture is built. They are used extensively as hay, pastures, soiling, silage, green manure, cover crops, and seed crops, and in addition are outstanding as soil builders.

Justification for Perennial Legume Root Study

In the Willamette Valley there are approximately 105,500 acres of perennial legumes under cultivation. This large acreage and the fact that no information has been available on the reactions of perennial legume roots in this region constitutes ample justification for this study. With such knowledge many problems of perennial legumes relating to: (1) soil conservation, (2) soil improvement, (3) increased plant production, and (4) more efficient soil utility in western Oregon will be determined.

Root investigations of these crops in other sections of the United States are indicative of its outstanding importance. However, the conditions under which these investigations were performed are not considered applicable to those which exist in this region. Under such circumstances it seemed desirable that the behavior of perennial legume roots in western Oregon be ascertained.

Statement of the Problem

The objectives of the study were to determine (1) what perennial legumes are best adapted to given soil types and (2) the characteristic rooting systems, the extent and zones of greatest root activity as influenced by soil types.

REVIEW OF LITERATURE

The literature as reviewed in connection with this thesis is as follows: (a) Previous Investigations on the Crops Studied, (b) Methods of Root Observations, and (c) Soil Properties Influencing Root Growth.

A. Previous Investigations on the Crops Studied:

A brief review of previous root investigations on the perennial legumes included in this study is presented.

A short description is included on the less common varieties.

1. Alsike clover (Trifolium hybridum)

Piper (44) in discussing the characteristics of this plant states: "The root system is relatively shallow, and on this account the plant does not withstand drowth." Hays (25) in making a comparative study of the root systems of various clovers found that the taproot of alsike clover at the end of one month was 9.5 inches long. At two months it was 2 feet 6 inches long.

Robbins (46) in his description of alsike clover states: "There are many secondary roots which become as large as the main taproot."

2. White clover (Trifolium repens)

White clover is a low, smooth, perennial legume which arises from a straight taproot. The plant possesses creeping stems which develop adventitious roots at the nodes.

Hays (25) studying clovers found that white clover at the age of one month had a taproot 5 inches long, and at two months its length was 2 feet.

Weaver (72) states: "White clover is a perennial legume with a root habit very similar to that of red clover, although somewhat finer, at least, during the first year of its development. Mature plants possess long, deeply penetrating taproots from which originate many profusely rebranched laterals."

3. Ladino clover (Trifolium repens latum)

Ladino clover is a very large variety of white clover. The flowers and trifoliate leaves are borne singly on long stems. These plant parts are similar to those of common white clover except they are less numerous and considerably larger. It is a perennial and like white clover produces stolons which have fibrous roots at the nodes.

Schoth (50) in describing the characteristics of this clover states that the root system of Ladino clover consists of a short taproot with numerous branches.

4. Strawberry clover (Trifolium fragiferum)

This clover is a perennial, low-growing, pasture legume, which spreads vegetatively by stolons that root at the nodes. The leaves, stems, and habit of growth are similar to those of white clover.

Strawberry clover is a palatable pasture plant and is relished by all classes of livestock and poultry. It is more generally used for pasture than for hay. The tolerance of the rooting system of this plant to seeped, saline, and alkali soils containing concentrations of salts that inhibit growth of other crops is of particular importance. However, the growth of this clover is not limited to such soils because it will thrive on low, wet, nonsaline soils as well. It will stand flooding without damage for considerable periods.

No published information is available on the root systems of this plant.

5. Red clover (Trifolium pratense)

Red clover is one of the most important legume forage crops.

Hays (25) in making a comparative study of the root systems of various clovers found that red clover at the age of five months had penetrated to a depth of 5 feet 8 inches. Shepperd (57) in studying the root systems of field crops at North Dakota observed that red clover on a two year old sod had roots extending to a depth of 4 feet. Ten Eyck (59) describes the root systems of red clover as follows: The main taproot upon reaching a depth of 2.5 feet divides into several small branches. These branch roots penetrate to a depth of 3 feet 9 inches. Near the crown, several large laterals are produced which form a heavy fibrous growth in the upper 18 inches of the soil.

Robbins (46) states in describing red clover: "It develops from a strong taproot which possesses an extensive system of laterals. The taproot reaches a depth of 3 to 6 feet."

Weaver (72) in studying red clover at Lincoln, Nebraska, in a rich, moist, silt loam found that at two and a half months a strong taproot with widely spreading and much branched laterals and an abundance of tubercles had developed. By the middle of August, several taproots, 5 to 7 millimeters in diameter were present. These tapered rapidly and at a depth of 9 inches were only a millemeter in thickness. They penetrated to a depth of 4.5 feet. At maturity, further development of the roots consisted largely in their deeper penetration and the growth of additional laterals. The roots penetrated straight downward to depths of 8 to 10 feet. A great mass of fine rootlets arose from the crown and first few inches of the taproot.

6. (Lotus corniculatus)

Lotus corniculatus is a long lived perennial which has shown considerable promise as a new forage and pasture crop. It has a crown similar to alfalfa and its stems are upright and from 6 to 36 inches tall. The root system of this crop is described as a deep taproot with many branches.

7. White Sweetclover (Melilotus alba)

White sweetclover, formerly a common roadside and waste-place plant throughout the country, is now an important forage, green manure, and cover crop.

Piper (44) in his discussion of this crop states that at the end of the first seasons growth its roots are large and fleshy and may extend to a depth of 6 feet or more. Weaver, Jean and Crist (69) studied sweetclover root development at Nebraska. They observed that at 30 days its root system had penetrated to a depth of 3 to 4 inches. At 63 days its roots had reached a depth of 9 inches to 1.5 feet and secondary roots were present which were similar to those of alfalfa. When the plants were 115 days old the roots had penetrated to a depth of 5.5 feet. At this age the large taproot tapered rapidly and most of the laterals occurred in the surface soil.

Weaver (72) found seven weeks old plants possessed strong taprrots which ran vertically downward to a depth of 2.6 feet. Laterals occurred through-out their full length. At four months the roots had penetrated to a depth of 5 feet and rarely more than two large branches occurred on a plant. Roots in thin stands were found to branch more. Small laterals clothed the taproot and large laterals.

8. Alfalfa (Medicago sativa)

Alfalfa is one of the most important forage crops in America.

Alfalfa is a deep feeder. The young plant usually sends down a single taproot, which as a rule takes a straight downward course. Often there is an abundance of small laterals just below the crown to a depth of 1 to 2 feet.

Hays (25) found that alfalfa at 5 months had penetrated to a depth of 6 feet 6 inches. Headden (27) describes the root system as "exceedingly simple". He found alfalfa extended downward 12 feet in a stiff clay soil.

The work of the above investigators and results of Cottrell (11), Shepperd (57), Ten Eyck (59), Duley (16), and Kiesselbach, Russel, and Anderson (32) proves that alfalfa is a deep feeder.

At the Kharkov Station in Russia a study of the roots of alfalfa was made. Observations were made when the plants were one, two, two and a half, three and a half, and four months old. Their analysis shows that growth of the root system of alfalfa continues uninterruptedly from germination to fructification. Roots grew most rapidly during the pre-flowering and actual flowering period. During this period the roots doubled their original length.

Weaver (72) states, "Alfalfa is a long-lived, very deeply rooted perennial. Upon germination, a strong taproot develops rapidly and penetrates almost vertically downward. It often reaches a depth of 5 to 6 feet the first season, 10 to 12 feet the second year, and may ultimately extend to depth of 20 feet or more. Often, both large and small branches are quite scarce, and the taproot is always the most prominent part of the root system. Under favorable soil conditions, nodules occur at all depths."

B. Methods of Root Observations:

Numerous methods have been used by investigators in observing the rooting systems of plants. They have been well reviewed, however, by Pavlychenko (43), Gibson (19), and Hansen (22), and it seems unnecessary to present here more than a brief summary of the methods used.

Root observation methods can be classified into five general groups: (1) Direct washing of roots from the soil by a steam of water, (2) Growing plants in prepared cultures, (3) Observation of roots from specially prepared pits, (4) Direct tracing of roots, and (5) Removal of soil from roots by means of a current of air.

The direct washing of roots from the soil by a steam of water includes such methods as those developed by Hales (21), Schubart (51), King (33), Hays (26), Schulze (52), Rotmistroff (47), Pavlychenko (43), Gibson (19), Hansen (22), and Tharp and Muller (60). The technique followed in these methods consisted of either digging a trench and studying the roots as they were washed from the soil, isolating a soil prism, caging it with a frame and washing the soil away by means of a steam of water.

Growing plants in prepared cultures for purposes of root study was first used by Nobbe (42), but Kraus (35), Haveler (24), Frank (18), Tucker and Von Seelhorst (64), Arker (3), Seelhorst and Frechmann (55), and Mielecki (39) have all done much in developing technique in such methods.

These methods chiefly consist of growing plants in water and specilly prepared soil containers.

Observation of roots from plants grown in specially prepared pits was a method developed by Rotmistroff (48). The root growth was determined by means of small windows in one side of the pit. This method has been little used because of the great expense involved in such a procedure.

The direct tracing of roots involves two separate techniques of procedure. Hellriedgel's method (28), which consists of studying the roots by means of a stell cylinder forced into the ground and Headden's method (27) of excavating them by means of a sharp instrument. This latter method has been greatly improved by the efforts of Weaver (72).

The removal of soil from the roots by a current of air was developed in Russia (34). This method consists of fixing the roots in place by means of a frame and then removing the soil by a current of air. This method can only be used when the soil has been carefully prepared.

C. Soil Properties Influencing Root Growth:

Plants exist in two environments, the atmosphere, and the soil. Although one is no more important than the other, it is generally agreed that the environment of the roots--the soil--is the seat of more complex plant activities than the atmosphere. Weaver (72) states, "Next to the living organisms which it supports, soil is perhaps the most complex, the most interesting and the most wonderful thing in nature."

Weaver and Clements (101) states: "The primary form of the root is governed first by the hereditary characters of the species of variety; but within the species or variety, root modifications are usually brought about by the operation of such factors as water content, aeration, soil structure, and nutrients."

1. Soil Moisture

The proportion of roots to tops may largely be controlled by the percentage of soil moisture. Roots of crops that develop in fairly dry soil must penetrate deeply and spread widely to secure their water supply. Kiesselbach (31) grew corn in soils with moisture ranging from 98 to 20 per cent of saturation. He concluded that root development varies inversely with the soil water content, and that plants which have their early growth in a relatively dry soil may be able to withstand drought better because of the greater surface exposed to the soil particles. Weaver (71) grew corn in fertile loess soil at water contents of 9 and 19 per cent, respectively, above the hygroscopic coefficient. In the wet soils the area of the tops was 82 per cent of that of the roots, but in the dryer soil the tops had only 46 per cent as great as area as the roots.

Weaver and Crist(70) working at Burlington, Colorado, concluded that available water was the controlling factor in root penetration in that region. Under favorable moisture conditions many of the native species penetrated the hard pan with their roots, whereas, normally they were limited by it. Metzger and Grandfield (38) found that when the subsoil had been dried by previous crops alfalfa roots failed to penetrate as deeply as when the subsoil had not been dried.

Considerable experimental work has been done to determine the ability of roots to pass through dry soil. Shantz (56) stated that certain trees of the African grasslands have the ability to extend their roots into dry soil. This is an exceptional case because the roots of ordinary crops do not possess this ability. They will only penetrate the length of the root cap into a soil reduced to the wilting coefficient.

2. <u>Soil Aeration</u>

In nutrient solutions, plants grow best where constant and thorough aeration is given. Cannon (6,7,8,9) in his studies of the relation of root systems to aeration found; (1) branching of roots increased with aeration, (2) root growth ceases when oxygen is completely removed from the soil, and (3) deficient oxygen supply is a limiting factor in plant growth. Bergman (4) states: "When aeration is provided the development of roots under submergence is not much, if at all, retarded as compared to roots of the plant in moist soil well aerated."

Dean (14) studying the effect of soil types and aeration on root growth concluded that unless the soil cultures were aerated plants established only shallow rooting systems, but where the soil was aerated roots ramified extensively. Arker (3) found that the rate of root and top growth in both water and soil cultures may be increased by forcing air through the medium.

Loehwing (37) grew sunflower, flax, wheat, and soybeans in soil that was aerated daily. Two months after planting, the roots of the plants grown in aerated soil were more numerous and more fibrous than those grown in unaerated soils.

The oxygen required by a plant varies with the temperature. Work of Cannon (6) confirms this fact. Miller (40) in discussing the relation of temperature to oxygen needs states: "There comes a point in the dermination of the oxygen content of the soil atmosphere when the growth of the root ceases because there is no longer a sufficient amount of this gas to supply the demands for energy correlated with physiological activities of higher temperatures."

3. Soil Structure and Texture

Diebold (15) found that where other factors are the same, roots penetrate more deeply and spread more widely in soils of loose structure than those that are more compact. Whitney (75), Haasig (20), and Hunter (30) in their root studies recorded similar results. Anderson and Cheyney (2) found that the length of the taproot, regardless of moisture, increased decidely from the finer to the coarser soils.

A hard compact soil limits the extent of root development to a marked degree. Weaver (68,74) observed that in compact soil the roots are more or less contorted or kinked, while the branching is decidely less than in soil of loose texture. Carlson (10) in studying the effect of soil structure on the character of alfalfa root systems observed that in compact soils all varieties and strains developed branch roots, while in open soil the taproots predominate.

Turner (65) studying the roots of the shortleaf pine found that in a silt loam soil 96.7 per cent of the root system was in the upper layers; while in fine sandy loam 87 per cent of the root system was in the upper layers.

Polle (45) found that the roots of plants growing in firm hard soil were more branched and had a greater absolute weight than those growing in loose soils.

4. Plant Nutrients

Nobbe (42) in an experiment so arranged that the nutrient salts were added only in definite regions of the soil, found that in the unfertilized portions of the soil the number of branches and roots both primary and secondary were small; while in the fertilized portions of the soil the number was strickingly large. Theil (61) and Haveler (24) secured similar results from their experiments.

Review of the literature on the effects of fertilizer on root growth is in disagreement. Seelhorst (54) in testing the effects of fertilizers on roots concluded that they increase the weight and depth of penetration, and because of this, plants receiving fertilizer were less likely to suffer from drought. Hellriegel (28) Ferrant and Sprague (17) in their root studies also show that fertilizers tend to produce extensive root development. Harris (23), Polle (45), Davis (13) and Tucker and Seelhorst (64) secured results contradictory from those of the above workers. They concluded that readily available nutrients reduce root growth.

The effect of phosphates in promoting root growth has long been recognized. Russell (49) found that dressings of phosphates are particularly valuable whenever greater root development is required. They are beneficial whenever drought is likely to develop because of inducement to the young roots to penetrate rapidly into the moist layers below the surface.

Crist and Weaver (12) working with barley found that phosphates did not noticeably increase root development.

Numerous experiments have shown that in every case where roots come in contact with layers of soil rich in nitrates they branch profusely and do not penetrate as deeply into the soil.

Frank (18) proved definitely the importance of nitrates in root development. He grew plants in such a manner that half the roots of each plant were in separate vessels. Calcium nitrate was added to one vessel and none to the other. He found that the vessel containing nitrate was filled with root growth, whereas, the vessel free of nitrate had only a few roots.

Muller and Thurgan (41) and Crist and Weaver (12) found vigorous root growth accompanies nitrogen salts.

5. Organic Matter

Organic matter has a direct influence on root development because of its effect on soil structure, aeration, moisture content and available nutrients.

Haveler (24) grew corn and bean plants in vessel that contained alternate layers of pure sand and fertile soil. The soil was rich in humus. He found that whenever the roots penetrated the fertile soil a profuse development of several root orders occurred. Weaver (74) in his study of white pine found that in most profiles the largest concentration of roots was found in the leaf mold area or duff. Livingston (36) observed that stable manure increased root growth in wheat.

6. Soil Reaction

Addoms (1) working with wheat found that seedlings grown in nutrient solutions high in H-ion concentration developed abnormal root systems.

Watenpaugh (67) in determining the influence of soil reaction on root development of alfalfa found that little or no growth of roots occurred in soils with a p H of 4.7, but when the p H was 5.5 to 6.2 root growth had good penetration. He also found a direct correlation between p H and the yield of alfalfa.

7. Temperature

Weaver (73) states: "If other conditions are favorable roots of various plants will grow at soil temperatures below 40° F and as high as 120° F." For most crops the most favorable temperature for root growth lies between 65° and 75° F.

Cannon (6) in studying the relation of root development to temperature and aeration found that normal shallow rooted desert plants would develop relatively deep root systems providing the temperature of the deeper soil was favorable. He also found that the growth rate varies directly with temperature, and that as the temperature increased more oxygen was required by the plant roots.

Weaver (73) in discussing response of roots to temperature states: "That soil temperatures have an influence on general plant growth is shown by the practice of florists of using bottom heat for certain plants."

8. Factors Limiting Root Penetration

Weaver and Crist (70) investigating root systems in the Great Plains found a calcareous hard pan over much of that region which tended to limit root penetration. The root system of alfalfa when grown in this region became so modified that it was hardly recognizable.

Schuster and Stephenson (53) in their discussion of causes of orchard failure in western Oregon, found that the majority of these were due to shallow soils having impervious layers which prevented penetration of the rooting systems.

Hard pans are not the only obstruction encountered by roots. Often their pentration is prevented by the water table. Headdin (27) found that roots of alfalfa cease to descend upon reaching the water table.

METHODS

A. Crops Selected:

Crops used in this study were: (1) Alsike clover (Trifolium hybridum), (2) White clover (Trifolium repens), (3) Ladino clover (Trifolium repens latum), (4) Strawberry clover (Trifolium fragiferum), (5) Red clover (Trifolium pratense), (6) Lotus (Lotus corniculatus), (7) White sweet-clover (Melilotus alba), and (8) Alfalfa (Medicago sativa), Grimm variety.

B. Selection of Soils:

Soil types that are important in legume production were selected for making this study.

Soils of western Oregon are classified into three general groups: (1) Recent alluvial soils, (2) Old valley filling soils, and (3) Residual hill soils.

Recent alluvial soils are young soils of the river and stream bottoms. They have uniform profiles, friable subsoils and are largely of sedimentary and basaltic origin. They include the most desirable agricultural soils of western Oregon. At present there are approximately 497,984 acres of these recently developed alluvial soils much of which is under cultivation.

The Chehalis soil series, which occupies the second bottoms, was selected to represent these recent alluvial soils because: (1) There are more acres of Chehalis under cultivation than any other soils series of this group; (2) It is of major importance for production of some perennial legumes such as alfalfa; (3) It is the most desirable agricultural soil in western Oregon; and (4) at high water season this soil is often subjected to erosion because of flooding.

Old valley filling soils are soils of the Willamette Valley floor. They include the more mature soils with moderately compact sub-soils and are largely of sedimentary and basaltic origin. At present there are approximately 916,000 acres of old valley soils of which a high percentage is cultivated.

The Willamette soil series was selected to represent the old valley soils because: (1) It is one of the most productive agricultural soils of western Oregon; (2) It is the only old valley soil generally used for the production of perennial legumes; and (3) there are more acres of Willamette soil under cultivation than any other series of this group.

Residual hill soils are composed of residues of rock materials weathered in place, and they are extremely variable in depth. This group of soils can be divided into two subgroups; those derived from weathering basaltic rock and those derived from sedimentary rock. At present there are approximately 3,347,400 acres of hill soils in western Oregon. While these soils are of great potential importance for legumes, the percentage under cultivation is relatively smaller than that of the other two series included in this study.

The Melbourne soil series was selected to represent the hill soils because: (1) This series is representative of residual soils of sedimentary origin; (2) This soil is becoming important in cover crop seed production; (3) Large burned-over as well as cleared areas of this land of varying topography are used as pastures. Therefore, a legume that will maintain itself under such conditions is needed; and (4) This soil series presents the most serious erosion problems of hill land in western Oregon during the winter season.

C. Location of Plots:

The Chehalis series and Willamette Series plots were located on Oregon State Agricultural College Experiment Station land. The former on the East Farm, and the latter on the Granger Farm.

The Melbourne series plot was located two and one-half miles west of Corvallis on the Gilbert Beech farm.

D. Planting:

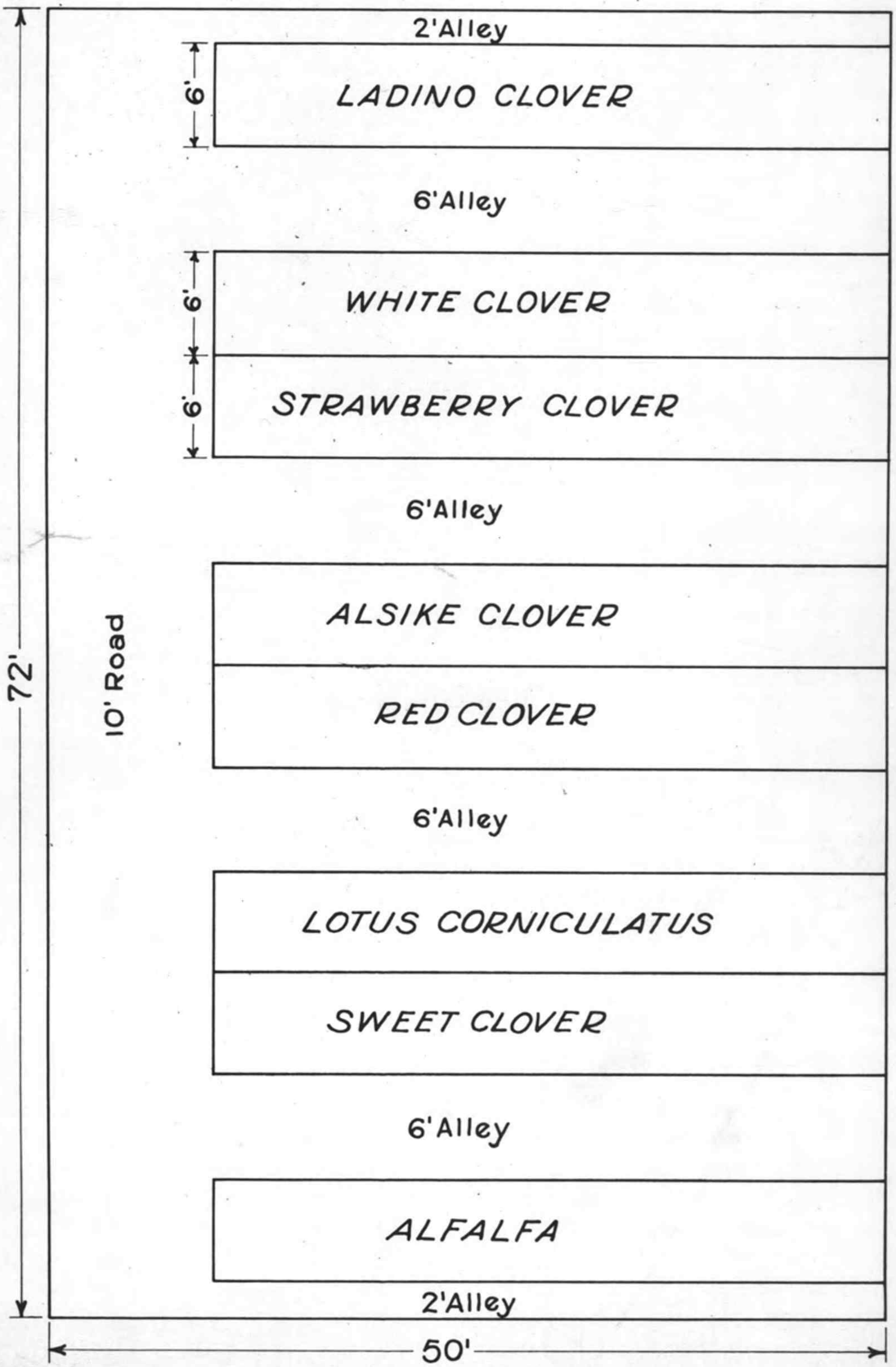
The seeding plan is shown in the planting chart, (page 23).

Seed bed preparation was such as is commonly practiced by good western Oregon farmers. The procedure followed was plowing, working down with disc, and harrow until reasonably fine, level, and firm. The plots were rolled previous to seeding so as to insure a firm seed bed.

The plots were seeded between April 13, and May 22, 1940, but because of failure to obtain stands of the following crops: alsike, white, Ladino, and strawberry clover, these were reseeded on October 12 and 19, 1940.

Plots were all seeded with a six-foot forage drill in the spring of 1940. However, in the reseeding of the previously mentioned crops, they were broadcast and raked in by means of small garden rake.

ROOT DEVELOPMENT STUDY



The crops were seeded at the following rates:

(1)	Alsike clover	6 lbs. per acre
(2)	White clover	6 lbs. per acre
(3)	Ladino clover	6 lbs. per acre
(4)	Strawberry clover	6 lbs. per acre
(5)	Red clover	11 3/4 lbs. per acre
(6)	Lotus corniculatus	6 lbs. per acre
(7)	White sweetclover	11 1/2 lbs. per acre
(8)	Alfalfa	11 1/2 lbs. per acre

All crops were seeded approximately one-half inch in depth and upon emergence excellent stands were achieved on all plots.

E. Root Observation Methods Used in This Study:

1. Iron Cylinder Washing Method

This method as described by Gibson (19) is as follows: A shallow trench was dug along the side of the plants to be studied. The soil was then worked carefully away from the roots. As this was being done a rough sketch of the rooting system was made and descriptive notes taken.

After the sketch was completed and notes taken a number of unmolested plants were selected for excavation and further study. These selected plants were removed by the use of iron cylinders, the width and length being determined by the size of the plants. The cylinder was forced around the plants in the simplest manner possible so as not to destroy any portion of the root system.

The cylinder and its contents were then lifted out of the ground and transported to the washing tank. If the soil was dry it was allowed to soak until thoroughly moistened. It was then washed from the roots by means of a fine stream of water.

After the roots were freed from the soil they were suspended in a tank of water and the different plants separated. This was a slow and tedious process and required considerable time. When the roots of the plants had been separated from each other, those plants that showed root damage were discarded.

The roots were then photographed.

Although this method proved very satisfactory in grass root studies, it had to be abandoned in this study because: (1) The cylinders needed for the removal of the roots were so large that it was practically impossible to remove a cylinder and its contents from the excavation site; (2) The soil column often broke in transporting the cylinder from the field to the washing table with subsequent root destruction; (3) This method became too expensive when new cylinders had to be made for each observation; and (4) Washing of soil from the roots required too much time.

2. Direct Tracing Method

The second method attempted in this study was the Direct Method as developed by Weaver (70). In brief, this method is as follows: A trench is excavated eight to twelve inches from the plants to be examined. The length of this trench is determined by the kind of plants to be studied, but it should be 2.5 feet wide and 5 to 7 feet deep.

The roots were freed from the soil by means of fine pointed ice pick. At the same time a rough drawing is made of the root system. After complete removal from the soil the roots were floated in water, arranged on black lacquer plate, and photographed.

Widely varying soil conditions existing in western Oregon makes the application of Weaver's method impractical. The plasticity and tenacity of these soils is very high because of the clay and colloidal content. These properties make it extremely difficult to work the soil away from the roots without damaging them seriously, and as the soil dries during the summer its removal from the roots becomes increasingly difficult. Because of this and of the great amount of time necessary to excavate roots, Weaver's method was not used.

3. Direct Washing Method

Root studies provide a key to the proper interpretation of the above ground plant development. However, to be of fullest value for such studies, the entire root systems of the plants must be made available and as a consequence their careful removal from the soil is necessary.

At the suggestion of G. R. Hyslop a very satisfactory method of excavating root systems was developed. The method used is a combination of the trench washing method as used by Schubert (51) and the direct method as used by Weaver (72).

The materials needed for this operation are simple and inexpensive. They consist of a pressure pump, shovel, ice pick, and water container.

In selecting plants for study it is very essential that they be representative of the population. The worker should keep in mind the effect of plant competition on the development of roots as well as the tops. Hence, typical plants surrounded by others of similar characteristics should be selected.

After selection of the plants a trench is dug as near to them as possible. Care should be taken to locate this trench to avoid destruction of any of the roots. The width, length, and depth of the trench should be such as to allow the investigator to move about freely while excavating the root systems. A small basin was dug immediately below the plants being excavated. This served to collect the water and soil from the washing process and to keep the remainder of the trench reasonably dry. When this basin became full the soil and water were bailed out.

A hand or power sprayer equipped with hose and nozzle for delivering a fine spray of water is necessary for this work. The proper adjustment of the nozzle is essential if maximum efficiency in time and labor required for removal of the root systems is desired. This adjustment will vary with soil type, seasonal conditions and the plants being excavated. The spray of water should be of such fineness and force that it has an efficient soil removing action but does not damage the roots.

After the nozzle has been properly adjusted, it is held two to four inches from the soil face and kept in continual motion. As the spray is applied, the ice pick is used in loosening those areas free of roots and to keep the soil face evenly washed. The investigator should be extremely careful not to dislodge large chunks of soil with the pick because this may result in root damage.

The washing procedure is as follows: The taproot of the plant is exposed first, then working from the bottom of the taproot to the top, the laterals are carefully freed of soil one at a time until the entire rooting system is excavated (Plate I). During this washing procedure the investigator should never touch the roots with his hands or with any instrument until they are entirely free of soil because of possibilities of damage.

In the last observations, a power pump was used intead of a small pressure pump. This proved very satisfactory

Plate I

Taproot is exposed; then working from the bottom of the taproot to the top, the laterals are freed one at a time.

and resulted in a great saving of time and effort.

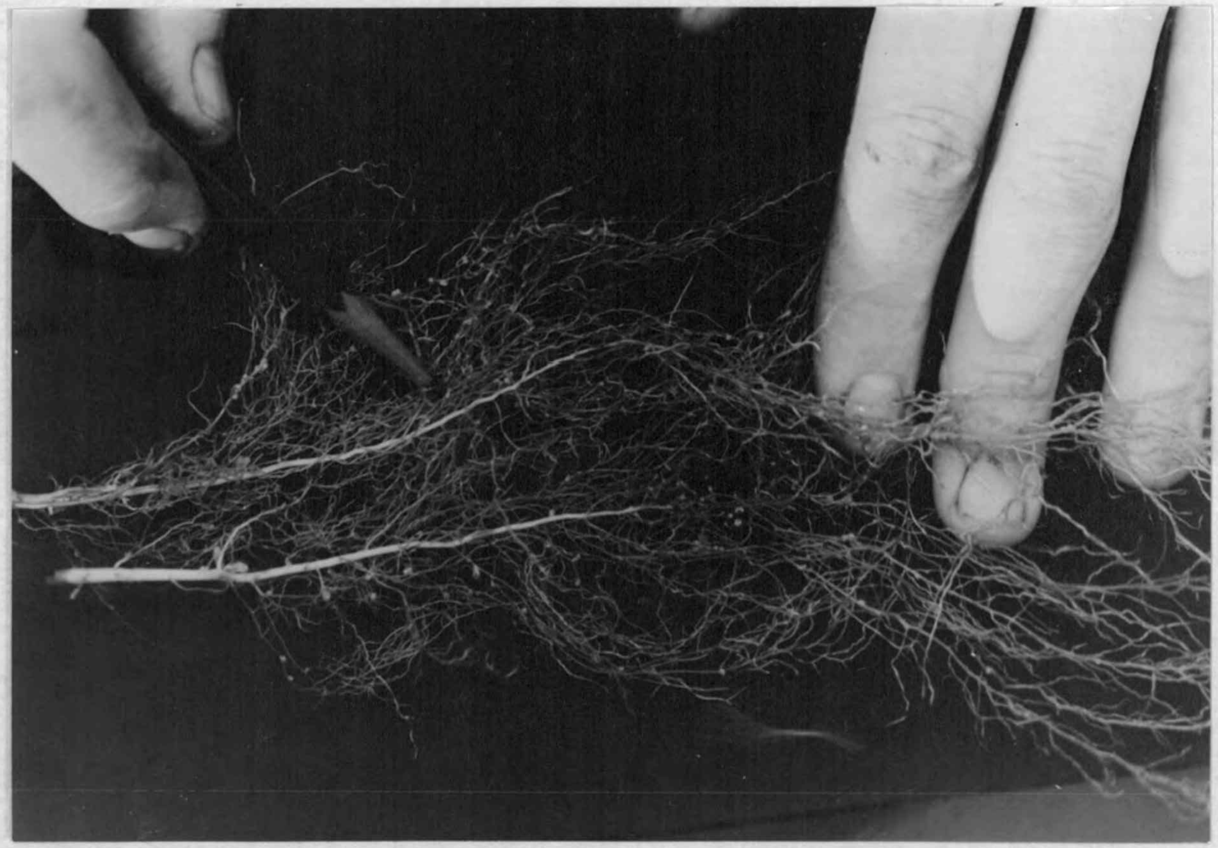
This process has certain disadvantages. During the winter season the trench often becomes filled with water and necessitates its removal before excavation of the roots can begin. In the dry season heavy soils become hard because of the high clay and collodial content, and time required for excavation lengthens. Experience indicates that these disadvantages are of minor importance in comparison to the advantages.

After removing the roots from the soil they were placed in glass jars and transported from the field to the floating tank.

The next step consisted of suspending the roots in water in a long shallow tank. Root systems of different plants were separated and thoroughly cleaned. This process was slow and tedious, but the author found that if the root systems were allowed to float in the tank for one-half hour to an hour the roots had a tendency to untangle. By inserting the hand under the roots and moving them up and down additional separation occurred. To further separate them, manipulation by hand during the period they were in the water was necessary, (Plate II). This process takes considerable time but proved quite satisfactory. When the plants had been worked free, those damaged were discarded.

Plate II

Root Systems and Debris are Separated



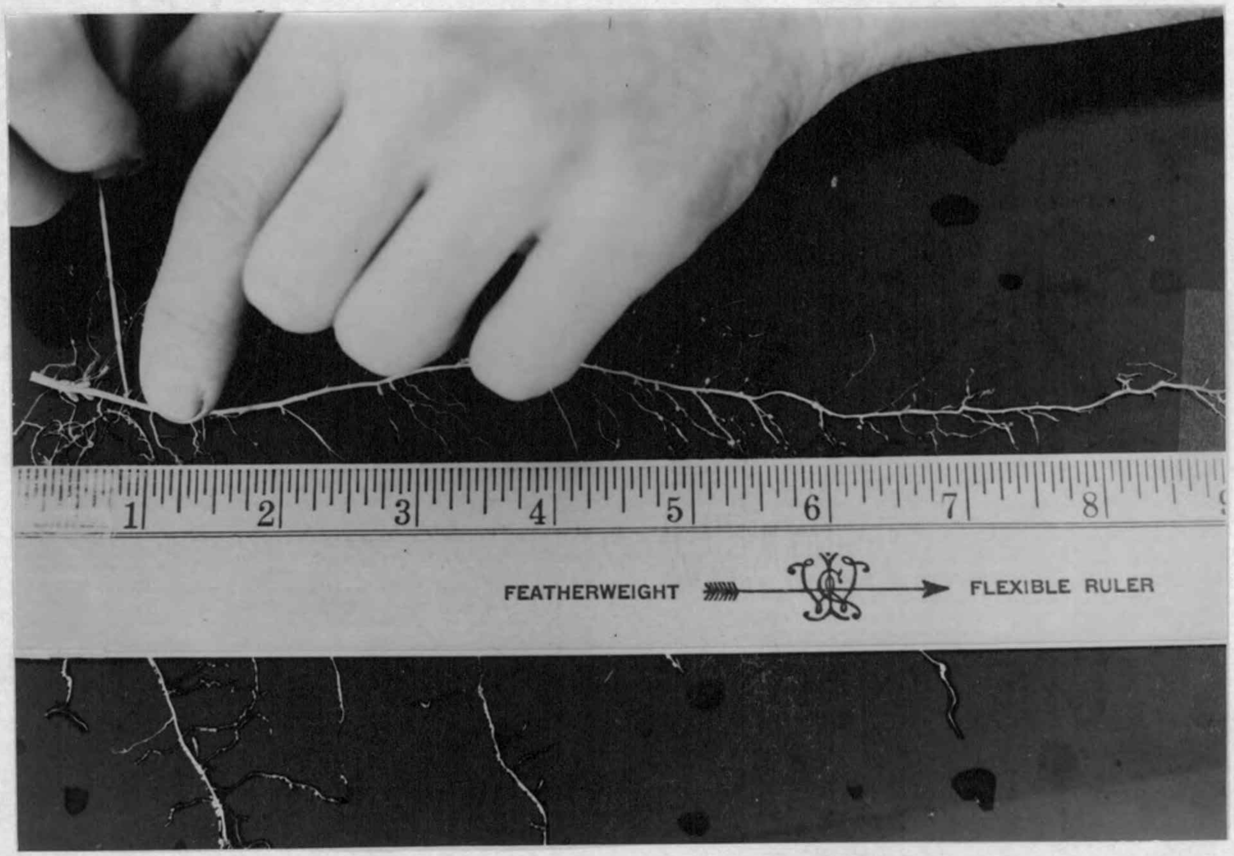
Nobbe (42) studying root systems, found that when roots were suspended in water and shaken up and down gently they returned to the position occupied in the soil. The author found this to be true with the larger roots but with the finer roots it was necessary to manipulate them into position.

After the damaged roots had been discarded, the root system or systems to be photographed were thoroughly cleaned and removed from the tank. The tank was then drained and flushed clean of any debris. A large plate, made of 14 guage iron, coated with black lacquer and somewhat larger than the root system was placed in the bottom of the floating tank as a photographic back ground. The tank was then refilled and the root systems refloated over the lacquered plate. After getting the roots in normal position the water was drained away slowly. By following this procedure the root systems would settle on the plate in that position. In this condition detailed notes of the root systems were taken, (Plate III). Upon completing the notes any remaining water was removed with blotters and the rooting system photographed immediately. When the roots were larger than the lacquered plate, they were photographed in the bottom of the tank.

This method of root excavation and photographing gave very satisfactory results in this study.

Plate III

Detailed Notes of the Rooting System are Taken.



The advantages of this method of root observation are as follows: (1) It is inexpensive; (2) The entire rooting system is obtained: (3) The position of all roots is easily seen; (4) A number of plants can be excavated at one time; (5) Competition between plant roots is very evident; (6) Any abnormal soil condition at the excavation site will be observed; and (7) The method is quite rapid.

F. Methods Used in Soil Analysis:

A physical and chemical analysis was made of each soil series in which root observations were made. This was considered necessary so as to standardize the information obtained from the root study.

1. Structure

To obtain a clear picture of the soil structure, the total pore space (capillary and non-capillary) was determined every 6 inches throughout the soil profile. This determination was made by the stell rim method, as developed by Stephenson (53).

2. Texture

A mechanical analysis was made every six inches throughout the soil profile by the method developed by Bouycoucos (5).

3. Chemical Analysis

Phosphorous as determined by Troug's method (63), organic matter as determined by Walkley's method (66), and nitrogen as determined by the Phenoldisolphonic acid method was obtained for each foot to the depth of root penetration. The acidity of the soil was determined by the color metric method.

A summary of these tests is given in Tables XXII, XXIII and XXIV.

WEATHER DATA

Climatic conditions are of great importance in determining plant development. The weather data, summarized in Table I, are considered necessary for an analysis of the results of this study.

As shown by this t able there is very little precipitation received in this region during the summer months. Such information is helpful in explanning the development of the root systems and their relationship to the feeding zones in the soils studied.

The low temperatures that existed during the winter months and the high perceipitation undoubtedly had a marked influence on root and top development of the crops studied.

During the December observations the soil was frozen to a depth of approximately 3.5 inches. However, there was

Table I

Weather Data for Corvallis, Oregon,
from
April 1, 1940, to April 7, 1941, inclusive

Month	Inches Precipitation	Temperature				Days Below 32°F	Greatest Daily Range
		Max.	Min.	Mean Max.	Mean Min.		
April, 1940	2.26	82.0	35.0	65.1	42.9	1	33
May	2.62	88.0	39.0	74.8	47.5	0	38
June	0.12	96.0	41.0	81.0	50.7	0	43
July	0.16	87.0	46.0	80.2	54.1	0	35
August	trace	100.0	48.0	84.2	54.1	0	45
September	2.75	88.0	41.0	75.4	53.9	0	35
October	4.14	83.0	34.0	66.8	49.6	0	27
November	4.46	61.0	26.0	51.7	37.1	4	24
December	4.71	63.0	20.0	50.4	37.7	5	24
January, 1941	4.38	57.0	28.0	49.4	37.2	6	20
February	1.65	63.0	31.0	56.5	37.6	2	29
March	1.22	77.0	30.0	65.1	40.6	1	37
April	1.27	64.0	40.0	60.0	43.9	0	21
Total	29.74					20	

Weather data obtained from E. F. Torgerson, cooperative observer, Oregon State College, Corvallis, Oregon.

no evidence of damage done to any of the crops. This freezing increased the time necessary to wash the roots from the soil.

EXPERIMENTAL RESULTS

Data secured in connection with this study will be presented in three sections: (A) Crops observed in the winter months; (B) Crops observed in the summer months; and (C) Physical and chemical properties of the soils used. This material is recorded in notes, tabulated measurements and in photographic records.

A. Crops Observed in the Winter Months

1. Alsike clover (Trifolium hybridum)

Data obtained from the five successive observations on alsike clover are presented in Tables II, III, IV, and V, and Plates IV to XII.

At the 28-day and 56-day observations the predominant feature of the root system in all three soil types was the taproot. Since the period following seeding was more favorable for germination and plant growth in the Melbourne soil, plants were more advanced than those in the Chehalis and Willamette soils. Plants observed at 84 days from date of seeding were approximately equal in all measurable factors. This similarity and the disappearance of differences existing between the growth of plants in the various plots, indicates that the influence of soil types was beginning to have some effect on root development. At a 112 days this influence was becoming greater as shown by the increase in diameter of the root systems, and by the weights of those plants growing in the Chehalis and Willamette soils.

Plants observed at 171 days from date of seeding indicated that at this stage the difference between plants growing on the various soil types were marked. Those plants growing in the Chehalis soil were superior to those in Willamette clay, and plants in the latter soil were superior to those grown in the Melbourne soil. However, root penetration was greater in the latter soil than either of the other two. This deeper root penetration was probably due to the lack of available plant nutrients, (Table XXIV), which demanded these plants to put forth a greater root system to acquire sufficient nutrients for plant growth. The root-top ratio of this soil as compared to those existing in the Chehalis and Willamette soils also justify such reasoning. Lack of moisture could produce similar results, but weather conditions existing in the Willamette Valley during the winter season, (Table I), ensures a plentiful supply of available water and it is unlikely that moisture had any direct influence on root penetration at this time.

For convenience the data on lateral growth is summarized in Table V. As is shown by this table and Plates X, XI, and XII, lateral root development was most extensive in the surface three inches of all soils. This was caused by the concentration of organic matter, available nutrients, and excellent structure which were conducive to root growth in this area, (Tables XXII, XXIII, and XXIV). Rooting systems in Chehalis clay loam were of greater diameter than in either Melbourne or Willamette clay. Plants grown in Willamette soil and Melbourne soil were modified by tillage pans present in these soils, (Table V and Plates X, XI, and XII). Plants upon encountering this compact zone in Willamette clay (8 to 13 inches, Table XXIII), tended to produce laterals which spread out over the tillage pan. Roots entering the compact region were contorted and reduced in size. In the Melbourne soil plants upon contacting the tillage pan (6 to 10 inches, Table XXIV), gave similar results, however, the branching was not so great as in the Willamette soil. Upon entering the tillage pan, roots in the Melbourne soil were somewhat reduced in diameter and the spread and number of laterals were reduced. As the root emerged from this compact zone the taproot increased in size and a larger number of laterals appeared.

The superior growth which was evident in all observations after the 56-day period in the Chehalis and Willamette soils appears to be due to the greater supply of available nutrients, especially nitrates and phosphorous, and excellent structure, that those soils have, (Tables XXII and XXIII), in comparison to the Melbourne soil, (Table XXIV).

Table II

Root and Top Development of Alsike Clover
Plants at Various Ages

Chehalis Clay Loam

Month of Observation	Nov.	Dec.	Jan.	Feb.	Apr.
Age (days from seeding)	28	56	84	112	171
Leaf development	coty-ledon	first	second	fourth	num-erous
Root penetration (inches)	2.5	4	5.5	6	15
*Weight of root (grams)	.0005	.0008	.0021	.0032	.0573
Depth of lateral roots (inches)	1	1	3	4	11
Diameter of root system (inches)	.5	1	2	3.5	10
Number of lateral roots	4	10	19	28	98
Length of top (inches)	.25	.5	.5	.75	3
*Weight of top (grams)	.0005	.0010	.0021	.0037	.0846
Root development (order)	first	first	second	second	second
Position of nodule formation		tap-root	first order	first order	second order

*Oven-dry basis 105° C

All results based on average of three or more plants

Table III

Root and Top Development of Alsike Clover Plants at Various Ages

Willamette Clay

Month of Observation	Nov.	Dec.	Jan.	Feb.	Apr.
Age(days from seeding)	28	56	84	112	171
Leaf development	coty-ledon	first	second	fourth	num-erous
Root penetration (inches)	2	3.25	4.5	6.5	15
*Weight of root (gram)	.0005	.0010	.0022	.0038	.0415
Depth of lateral root (inches)	1	2	2.25	4	10
Diameter of root system (inches)	.5	1	1.5	3	8
Number of lateral roots	4	10	17	26	80
Length of top (inches)	.5	.5	.5	1	2.5
*Weight of top (grams)	.0005	.0013	.0026	.0049	.0810
Root development (order)	first	first	second	second	third
Position of nodule formation		tap-root	first order	first order	second order

*Oven-dry basis 105° C.

All results based on average of three or more plants

Table IV

Root and Top Development of Alsike Clover Plants at Various Ages

Melbourne Clay

Month of observation	Nov.	Dec.	Jan.	Feb.	Apr.
Age (days from seeding)	28	56	84	112	171
Leaf development	first	second	third	fourth	numerous
Root penetration (inches)	2.5	4.25	4.25	6	18
*Weight of root (grams)	.0005	.0015	.0018	.0030	.0386
Depth of lateral roots (inches)	1	2	2.5	4.75	16
Diameter of root system (inches)	1	2	2	2	7
Number of lateral roots	7	19	21	34	85
Length of top (inches)	.5	.5	.5	1	2
*Weight of top (grams)	.0005	.0020	.0021	.0035	.0363
Root development (order)	first	second	second	second	third
Position of nodule formation	tap-root	tap-root	first order	first order	third order

*Oven-dry basis 105° C.

All results based on average of three or more plants

Table V

Number of Lateral Roots per Inch Sections of Taproot of
ALSIKE CLOVER
at Different Depths and at Successive Ages in Three Soil Types

Depth of Section of taproot	SOIL TYPE											
	Chehalis Clay Loam				Willamette Clay				Melbourne Clay			
	Days from Seeding				Days from Seeding				Days from Seeding			
	56	84	112	171	56	84	112	171	56	84	112	171
inches												
0-1	6	9	12	19	5	9	10	21	12	9	13	16
1-2	3	6	8	15	5	6	7	13	6	8	8	14
2-3	1	4	5	9		2	5	12		3	5	7
3-4			3	10			2	6			4	7
4-5				8				8			3	5
5-6				9				7				5
6-7				10				8				4
7-8				10				5				0
9-10				7				5				7
10-11				5				3				7
11-12												8
12-13												4
13-14												4
14-15												2
15-16												
16-17												
17-18												
18-19												
19-20												

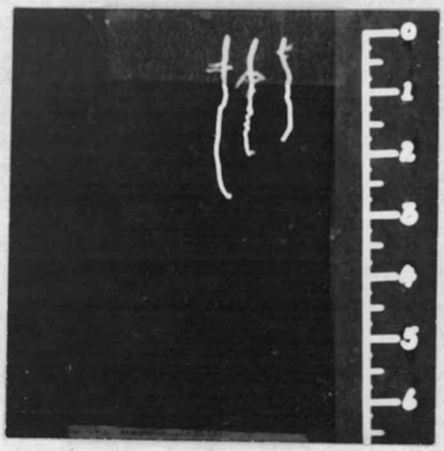
Plate IV

ALSIKE CLOVER

Root Development at 28 Days from Time of Seeding on

Chehalis Clay Loam

Willamette Clay



Melbourne Clay

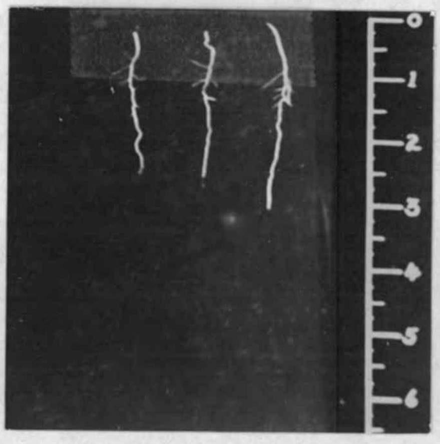
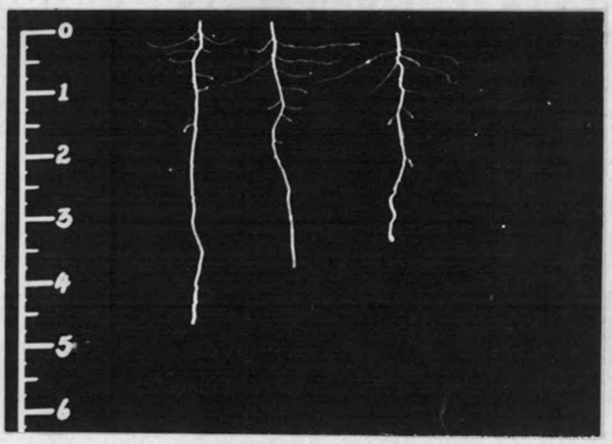


Plate V

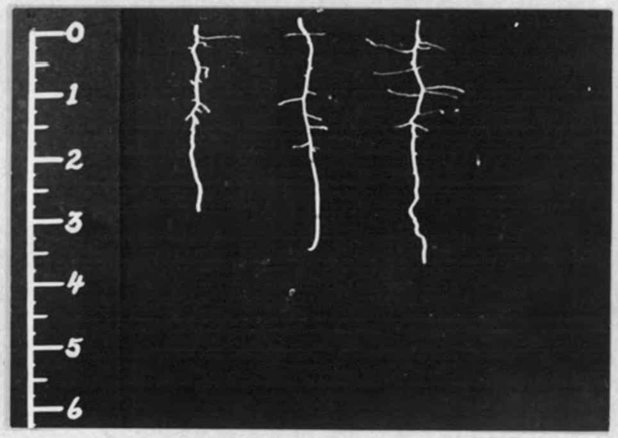
ALSIKE CLOVER

Root Development at 56 Days from Time of Seeding on

Chehalis Clay Loam



Willamette Clay



Melbourne Clay

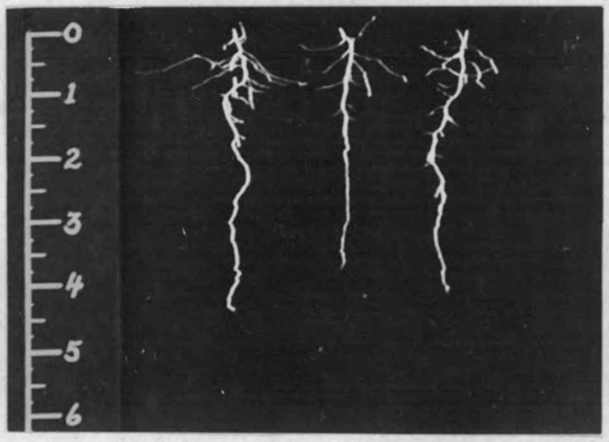
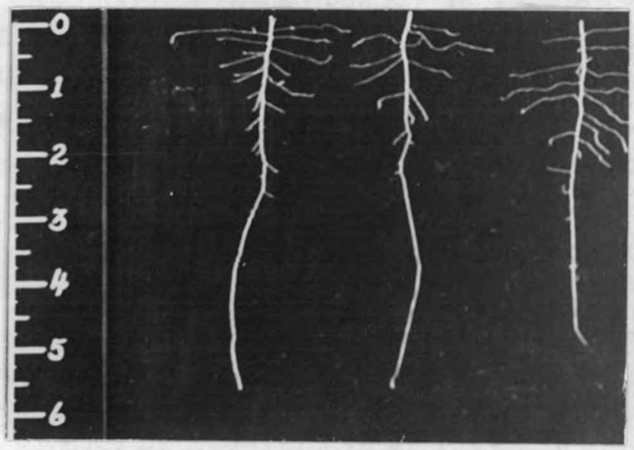


Plate VI

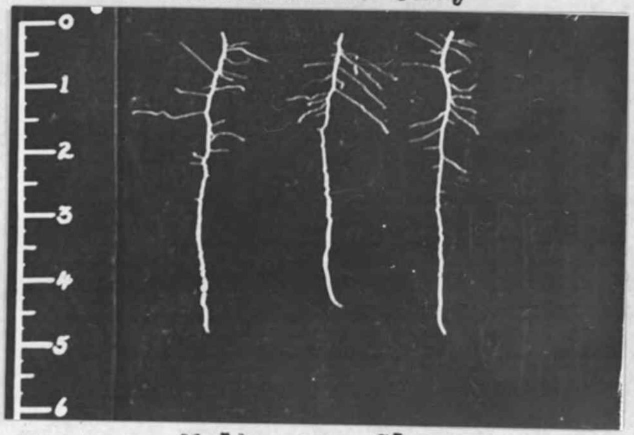
ALSIKE CLOVER

Root Development at 84 Days from Time of Seeding in

Chehalis Clay Loam



Willamette Clay



Melbourne Clay

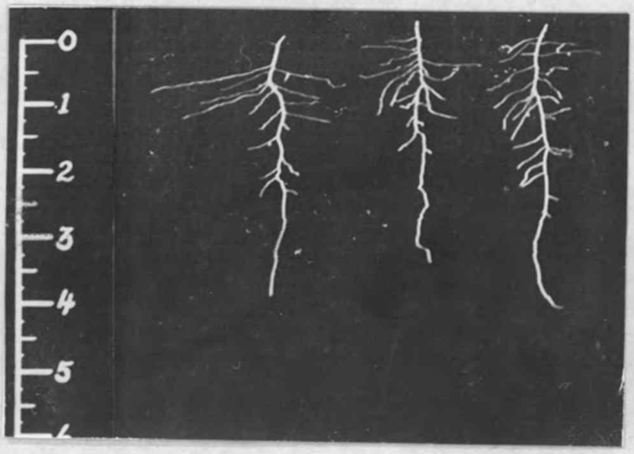


Plate VII

ALSIKE CLOVER

Root Development at 112 Days from Time of Seeding on

Chehalis Clay Loam

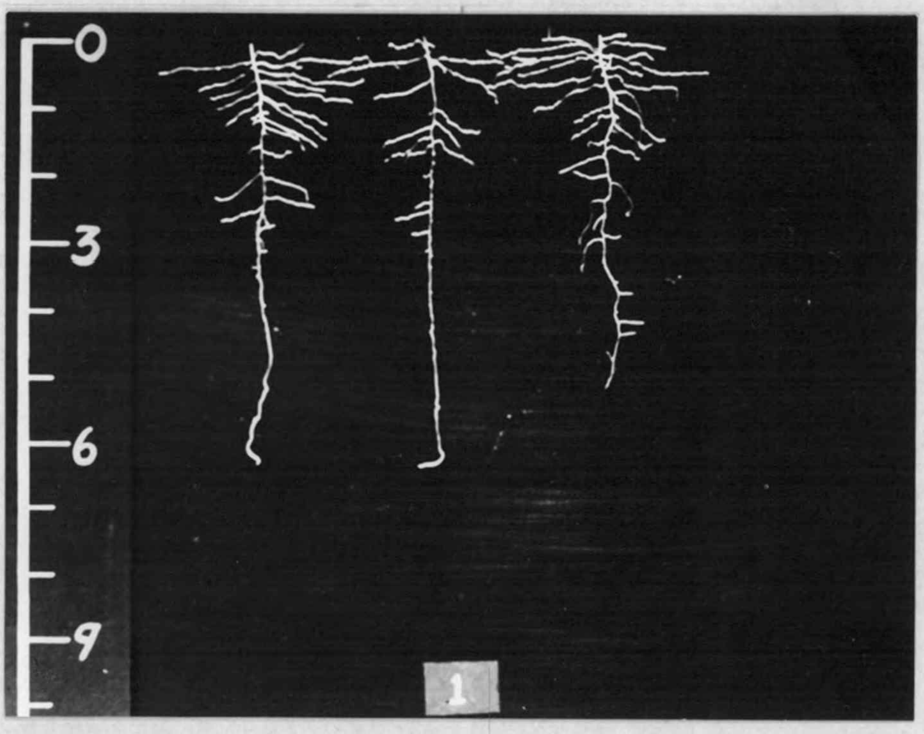


Plate VIII

ALSIKE CLOVER

Root Development at 112 Days from Time of Seeding on

Willamette Clay

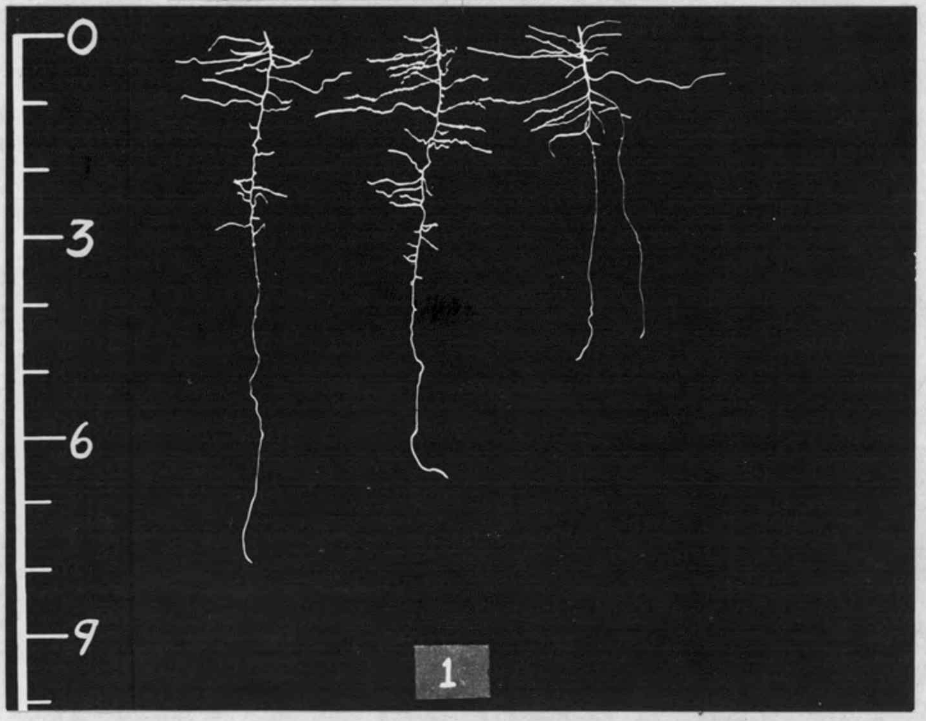


Plate IX

ALSIKE CLOVER

Root Development at 112 Days from Time of Seeding on

Melbourne Clay

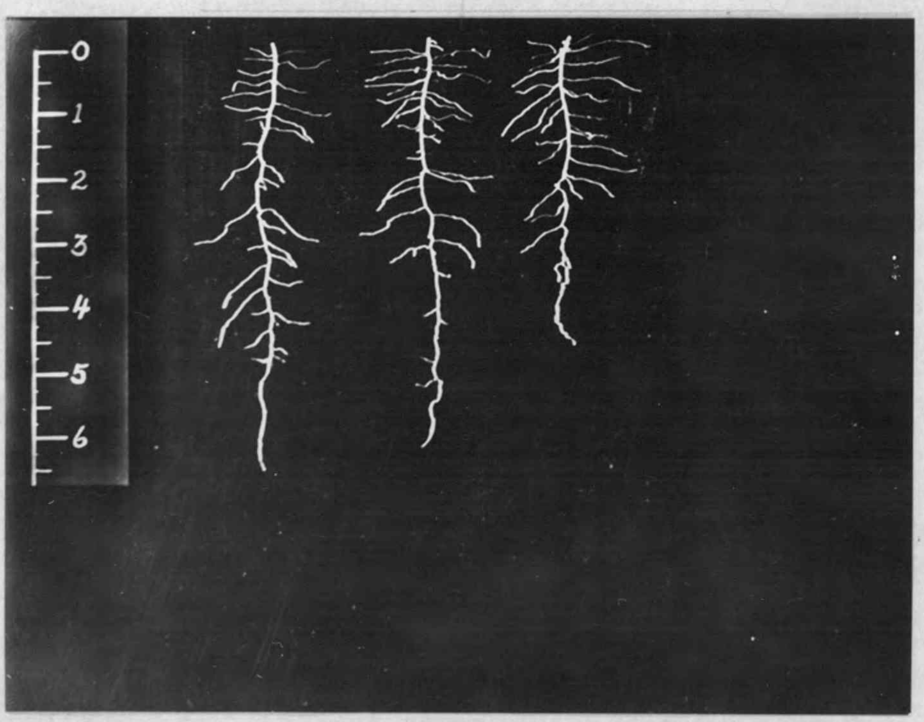


Plate X

ALSIKE CLOVER

Root Development at 171 Days from Time of Seeding in

Chehalis Clay Loam

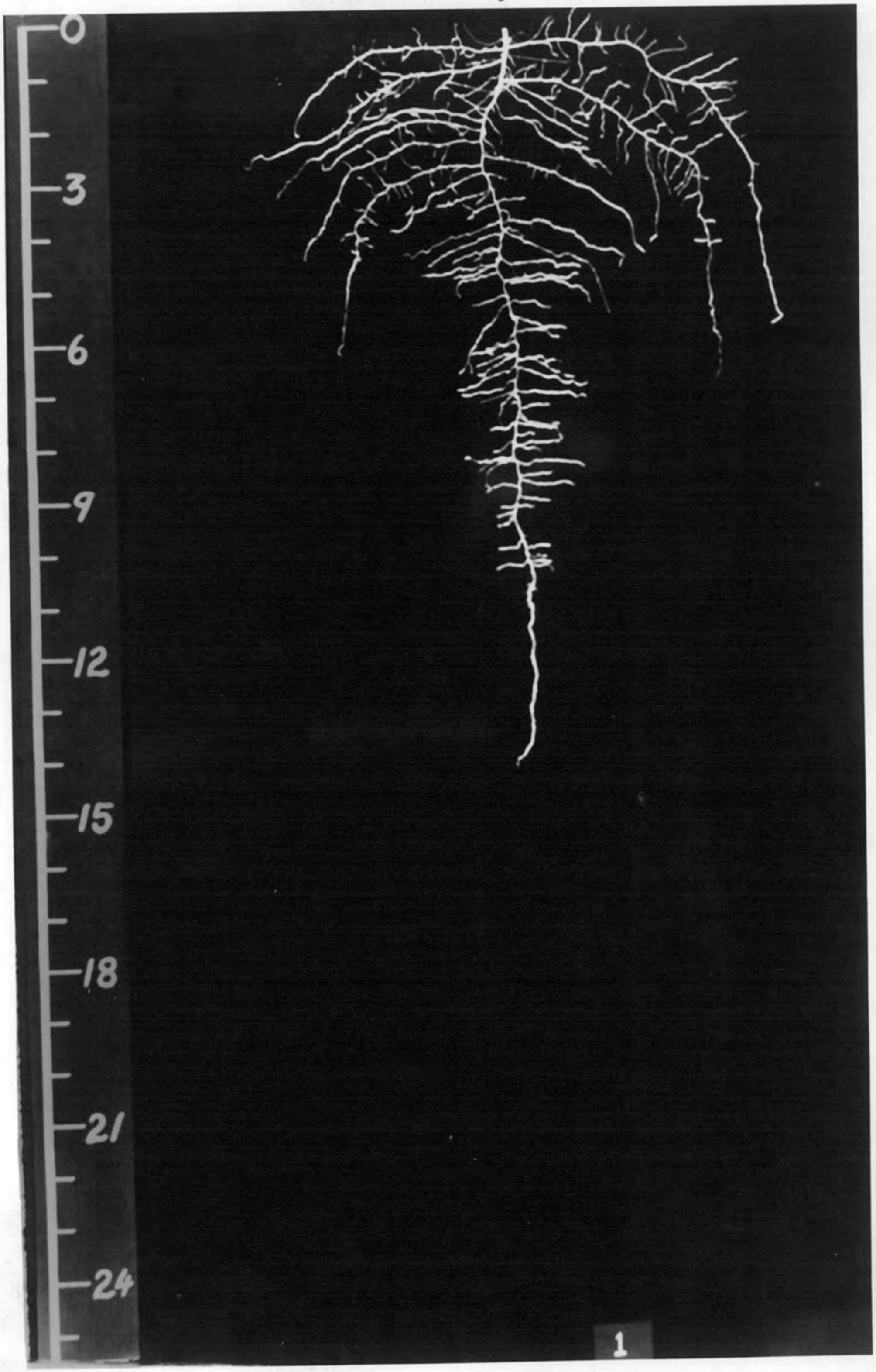


Plate XI

ALSIKE CLOVER
Root Development at 171 Days from Time of Seeding in

Willamette Clay

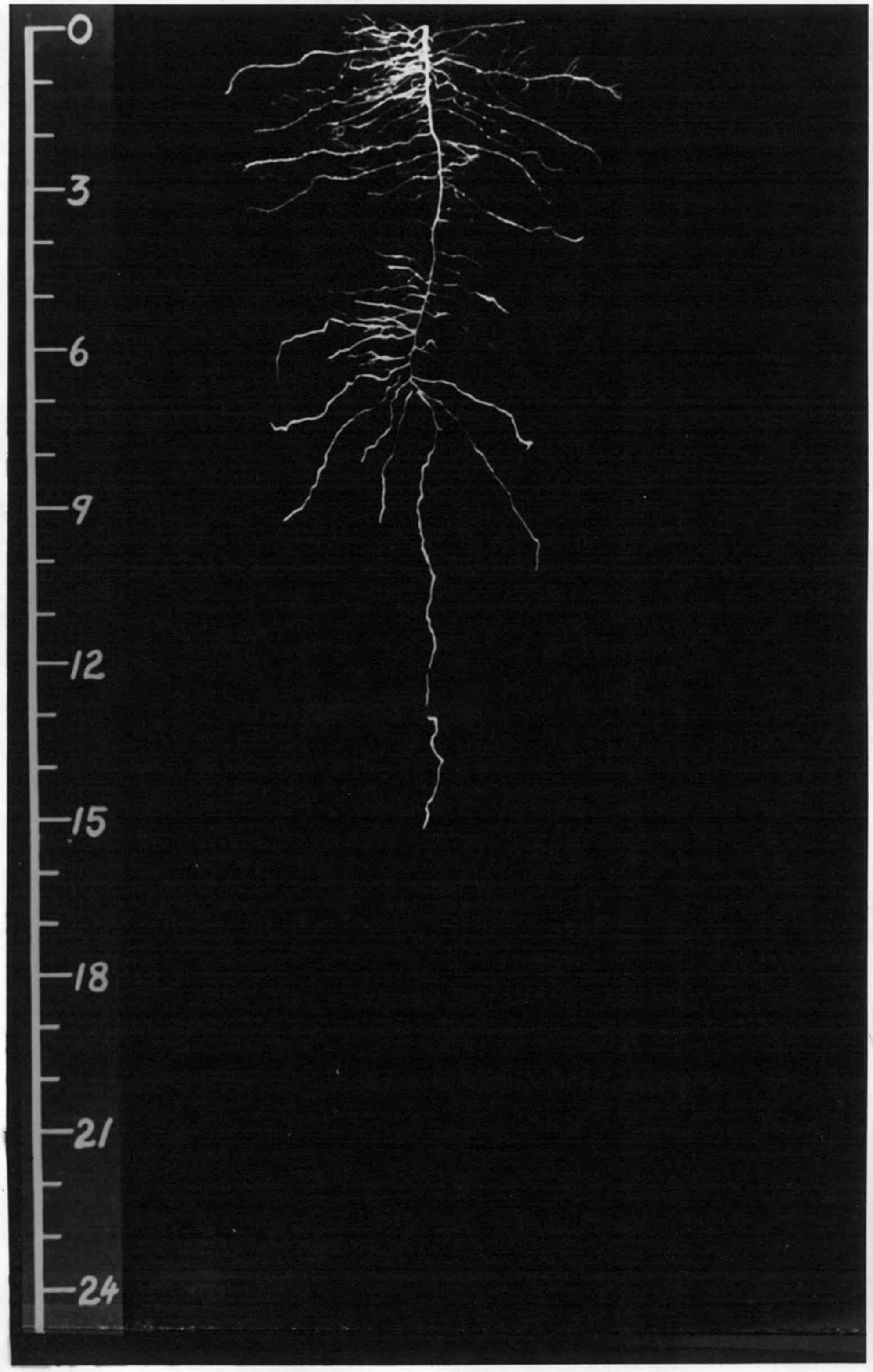
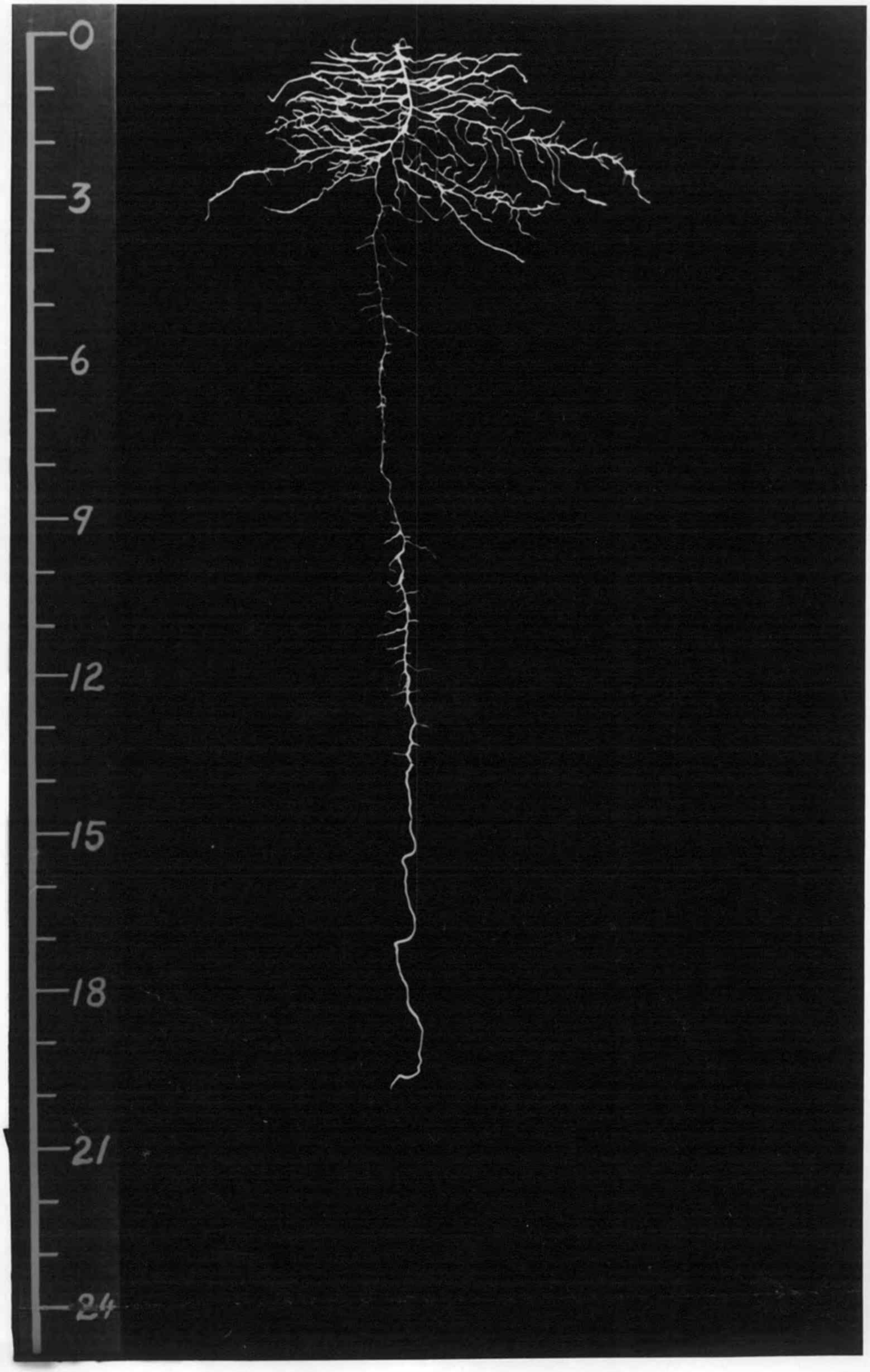


Plate XII

ALSIKE CLOVER
Root Development at 171 Days from Time of Seeding in

Melbourne Clay



Alsike Clover at Early Bloom Stage in Chehalis Clay Loam

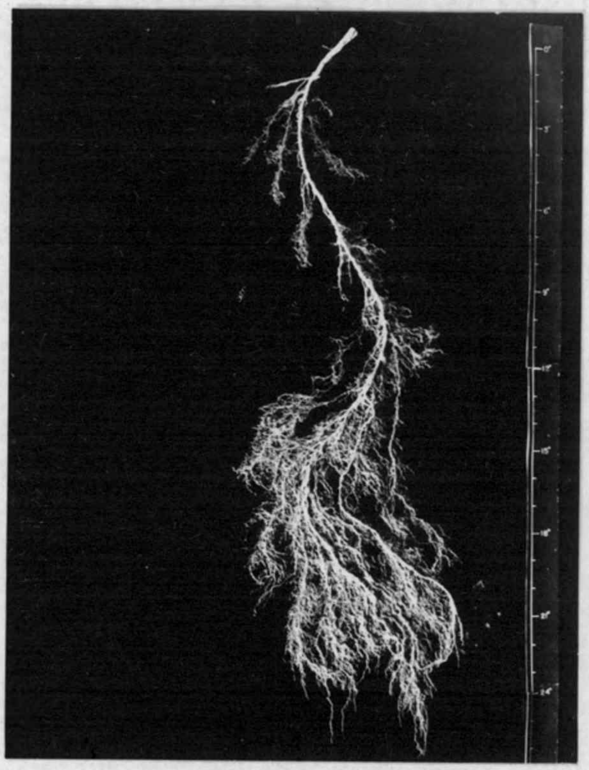
A planting of alsike clover made in the spring of 1940 showed a more rapid root development than the plantings made in the fall. An observation was made in early August, 86 days from the date of seeding, when the plants were in the early bloom stage. At this time the tops were 11 inches tall and the root system, (Plate XIII) extended to a depth of 26 inches. It consisted of a taproot with numerous laterals. In the surface 13 inches of soil, laterals were short and dry in appearance. The feeding zone of the root system, at this time, was below the 15 inch level, where numerous large laterals were found which penetrated the soil to a greater depth than that of the taproot. A large number of third order roots from one to two inches in length were present; the abundance of these small roots suggests an inadequate moisture supply. Tubercles were abundant in the lower portion of the rooting system. This pattern of root system is most likely caused by the reduction of moisture in the surface soil to such an extent that it is incapable of supporting root growth. Because of this the roots are forced deeper to secure their moisture and plant nutrients.

Plate XIII

ALSIKE CLOVER

Root Development at Early Bloom Stage in

Chehalis Clay Loam



2. <u>White clover</u> (Trifolium repens)

Measured factors as determined in connection with root development studies on white clover, (Tables VI, VII, VIII, and IX, and Plates XIV to XXII) are similar to those observed in connection with alsike clover. During the first three excavations little influence of soil types was visible. However, the 112 and 171-days observations show that some influence of soil types is appearing. Increase in plant weights, diameter of roots, number of laterals, and general appearance signify this.

At the 171 day observation, the taproot was the prominent portion of the root system of plants growing in the Melbourne clay. On plants in the Chehalis and Willamette soils, lateral root development was greater than that of the taproot. Depth of root penetration was greatest in those plants growing in the Melbourne soil. This result, as in the case of alsike clover, was probably caused by lack of available nutrients.

Lateral root development in white clover was most extensive in Chehalis and least in the Melbourne soil, (Plate XX, XXI, and XXII). Lateral branching in the Willamette soil was abundant throughout the length of the taproot as it was in the Chehalis soil, (Table IX), but the laterals of these plants in Chehalis were more extensive. Upon entering the tillage pan in the Willamette soil, (8 to 13 inches, Table XXIII), extension of laterals was reduced to a minimum, (Plate XXI). In the Melbourne soil, as is indicated by Table IX and Plate XXII, the tillage pan, (6 to 9 inches, Table XXIV), cuased a reduction in the number and spread of laterals. Upon penetration of the tillage pan by the taproot the number and spread of laterals increased again. Explanation of such results is that the soil lying below the tillage pan in Melbourne clay,(Table XXIV), has a more open structure. The number of laterals in a given section of taproot and the depth of lateral root formation increases with age,(Table IX).

Nodules appeared first on those plants in Melbourne clay. This was due to favorable conditions at the time of seeding.

As is shown by the measured factors, Chehalis clay loam is first, Willamette clay second, and Melbourne clay third in the production of vigerous and more extensive root systems. As shown by Tables XXII, XXIII, and XXIV these soils rank correspondingly in both plant nutrients and structure which probably accounts for the difference in growth.

Table VI

Root and Top Development of White Clover
Plants at Various Ages

Chehalis Clay Loam

Month of observation	Nov.	Dec.	Jan.	Feb.	Apr.
Age (days from seeding)	28	56	84	112	171
Leaf development	coty-ledon	first	second	third	stolons
Root penetration (inches)	2.5	4.5	5.5	7	14
*Weight of root (grams)	.0006	.0011	.0019	.0039	.0835
Depth of lateral roots (inches)	1	2	2	4	10
Diameter of root system (inches)	1	1.5	2.5	4.75	9
Number of lateral roots	3	10	14	34	127
Length of top (inches)	.5	.5	.5	1	2
*Weight of top (grams)	.0007	.0013	.0020	.0065	.1335
Root development (order)	first	first	second	second	third
Position of nodule formation		tap-root	first order	first order	second order

*Oven-dry basis 105° C

All results based on average of three or more plants

Table VII

Root and Top Development of White Clover
Plants at Various Ages

Willamette Clay

Month of observation	Nov.	Dec.	Jan.	Feb.	Apr.
Age(days from seeding)	28	59	84	112	171
Leaf development	coty-ledon	first	second	third	stolons
Root penetration (inches)	2	4	5.25	7.8	14
*Weight of root (grams)	.0005	.0013	.0023	.0051	.0743
Depth of lateral roots (inches)	1	1.5	3	5	12
Diameter of root system (inches)	.5	1	2	3	8
Number of lateral roots	5	12	19	29	80
Length of top (inches)	.5	.5	.75	1	2
*Weight of top (grams)	.0005	.0016	.0027	.0077	.0866
Root Development (order)	first	first	second	second	third
Position of nodule formation		tap-root	first order	first order	second order

*Oven-dry basis 105° C

All results based on average of three or more plants.

Table VIII

Root and Top Development of White Clover
Plants at Various Ages

Melbourne Clay

Month of observation	Nov.	Dec.	Jan.	Feb.	Apr.
Age(days from seeding)	28	56	84	112	171
Leaf development	first	first	second	third	num-erous
Root penetra-tion (inches)	2.5	4.25	5	6	19
*Weight of root (grams)	.0006	.0012	.0025	.0027	.0273
Depth of lateral roots (inches)	2	2	3.25	4	17
Diameter of Root system (inches)	1.4	1.5	2	2.5	6
Number of lateral roots	9	12	22	24	123
Length of top (inches)	.75	.75	.75	1	1.5
*Weight of top (grams)	.0007	.0015	.0027	.0035	.0287
Root develop-ment (order)	first	first	first	second	third
Position of nodule formation	tap-root	tap-root	first order	first order	second order

*Oven-dry basis 105^{o} C

All results based on average of three or more plants.

Table IX

Number of Lateral Roots per Inch Sections of Taproot of
WHITE CLOVER
at Different Depths and at Successive Ages in Three Soil Types

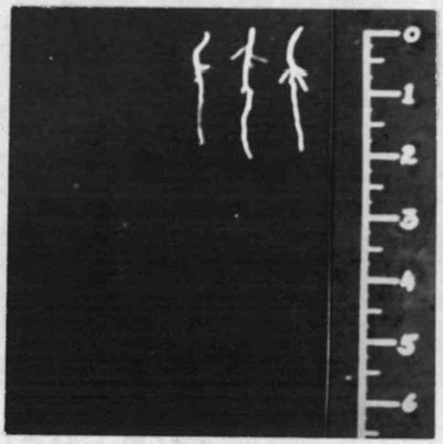
Depth of Section of taproot	SOIL TYPE											
	Chehalis Clay Loam				Willamette Clay				Melbourne Clay			
	Days from Seeding				Days from Seeding				Days from Seeding			
	56	84	112	171	56	84	112	171	56	84	112	171
inches												
0-1	6	8	11	10	6	10	9	12	7	9	10	15
1-2	5	5	8	9	6	5	6	9	5	7	6	9
2-3		2	6	7		3	5	8		5	3	5
3-4			4	13		2	3	8			3	5
4-5				10			3	9			1	4
5-6				13				7				7
6-7				12				5				7
7-8				13				5				7
8-9				14				4				9
9-10				14				4				9
10-11				10				3				10
11-12				3				3				9
12-13												8
13-14												8
14-15												7
15-16												8
16-17												2
17-18												
18-19												
19-20												

WHITE CLOVER

Root Development at 28 Days from Time of Seeding on

Chehalis Clay Loam

Willamette Clay



Melbourne Clay

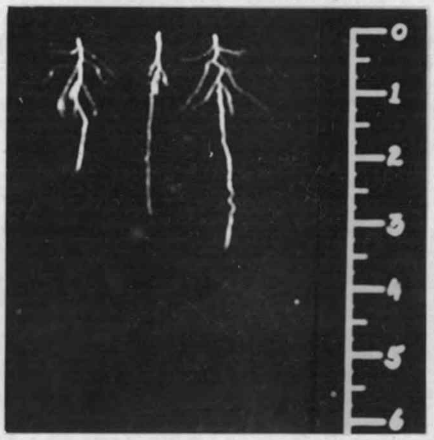
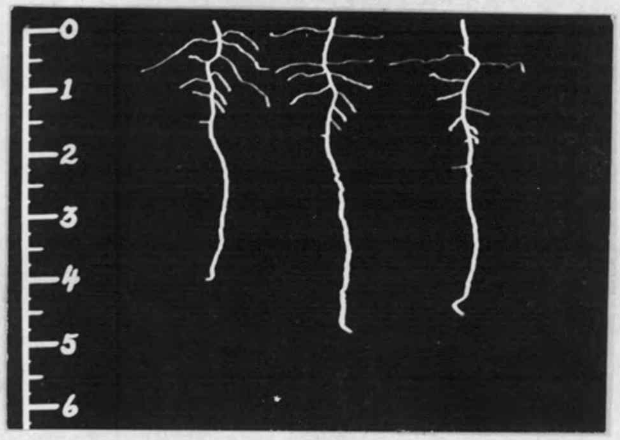


Plate XV

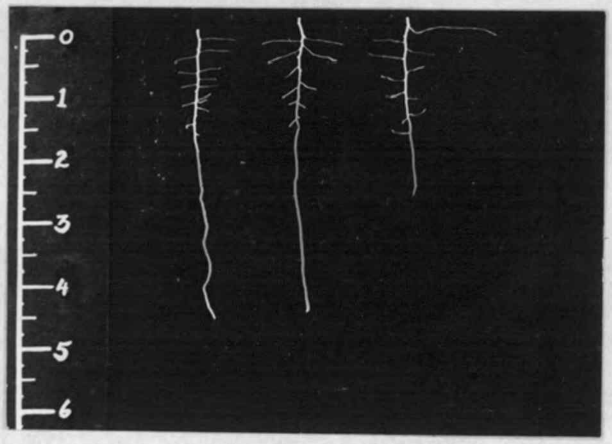
WHITE CLOVER

Root Development at 56 Days from Time of Seeding on

Chehalis Clay Loam



Willamette Clay



Melbourne Clay

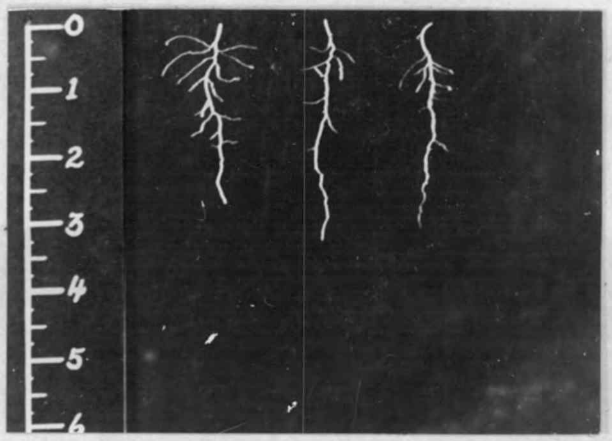
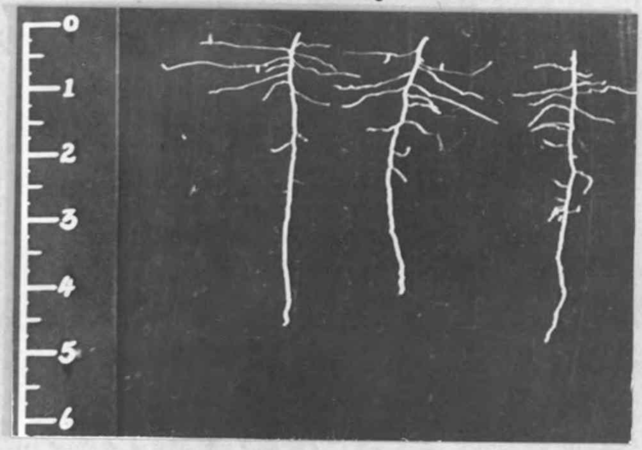


Plate XVI

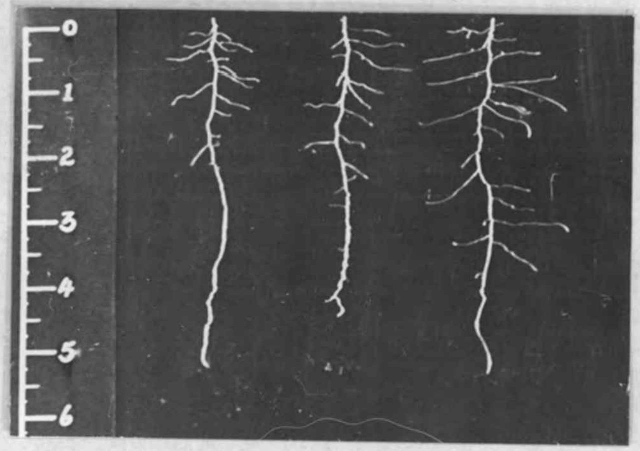
WHITE CLOVER

Root Development at 84 Days from Time of Seeding on

Chehalis Clay Loam



Willamette Clay



Melbourne Clay

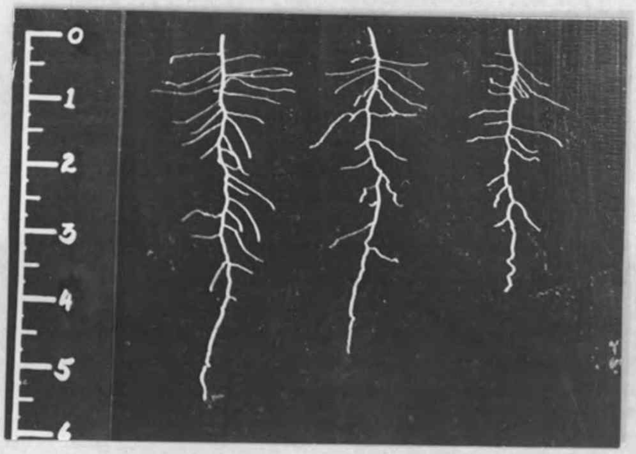


Plate XVII

WHITE CLOVER

Root Development at 112 Days from Time of Seeding on

Chehalis Clay Loam

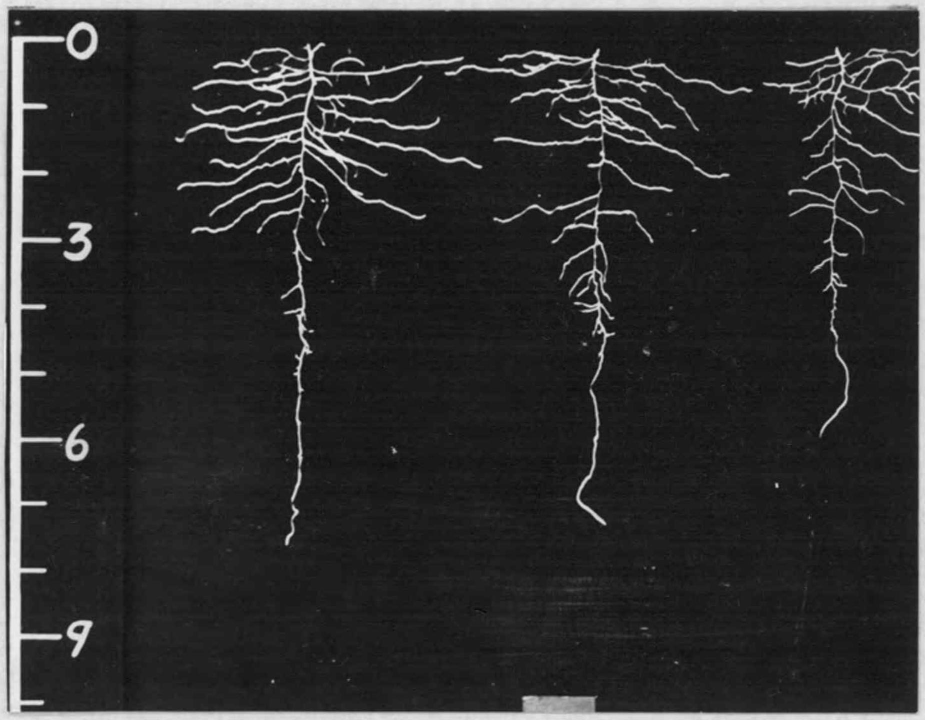


Plate XVIII

WHITE CLOVER

Root Development at 112 Days from Time of Seeding on

Willamette Clay

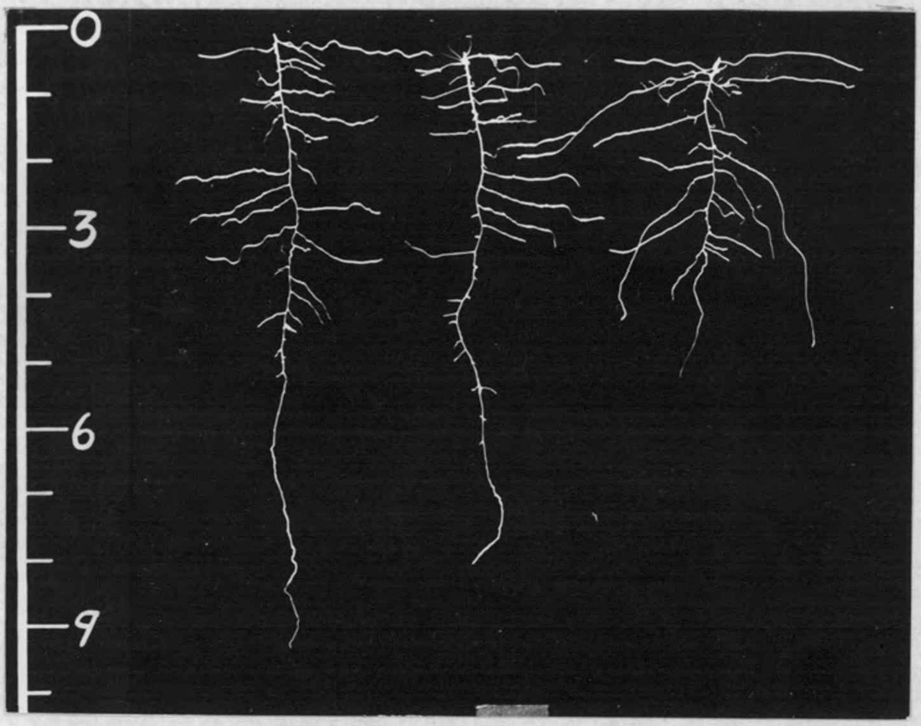


Plate XIX

WHITE CLOVER

Root Development at 112 Days from Time of Seeding on

Melbourne Clay

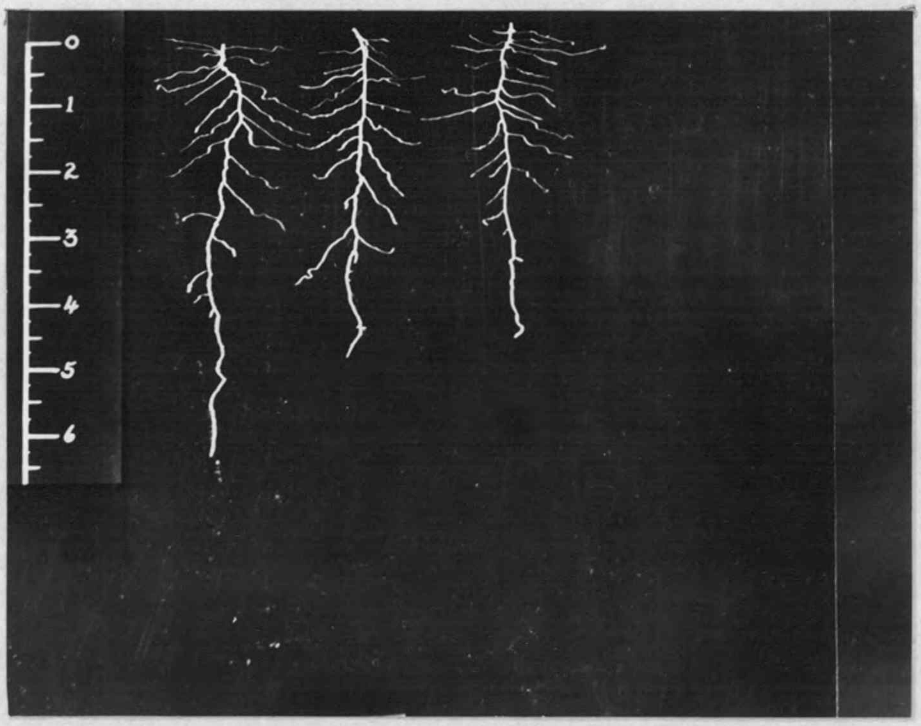


Plate XX

WHITE CLOVER
Root Development at 171 Days from Time of Seeding in

Chehalis Clay Loam

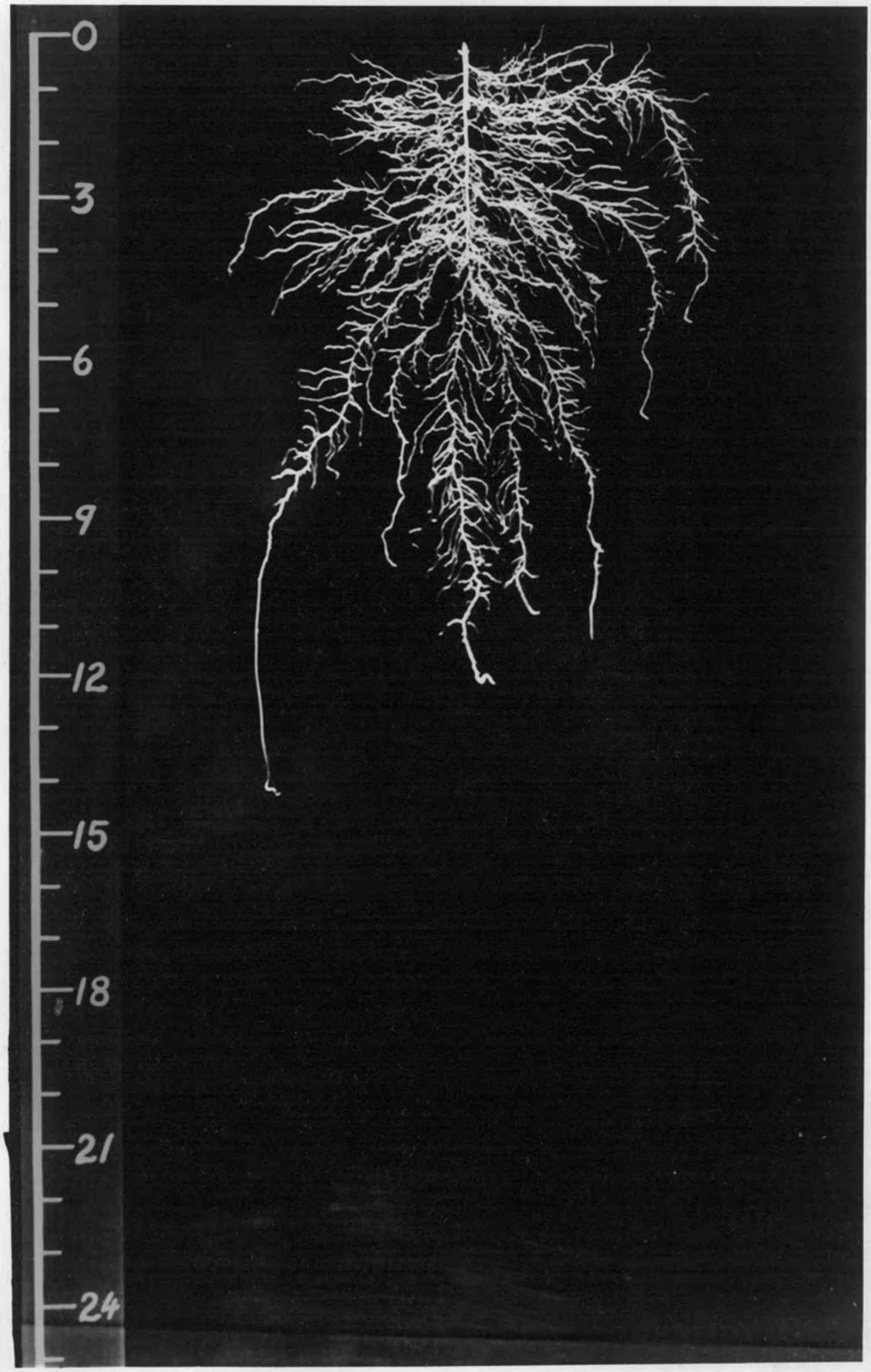


Plate XXI

WHITE CLOVER
Root Development at 171 Days from Time of Seeding in

Willamette Clay

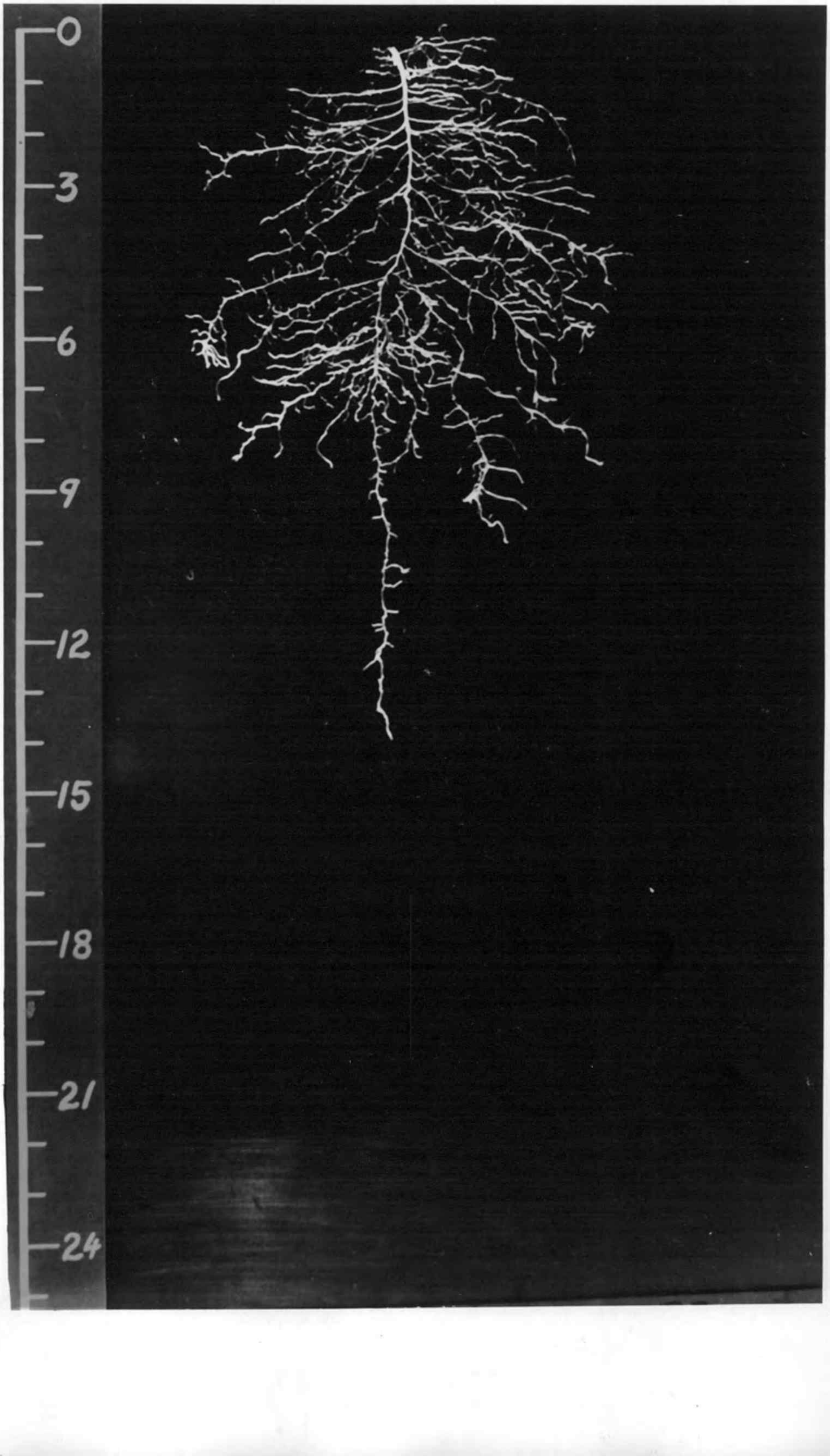
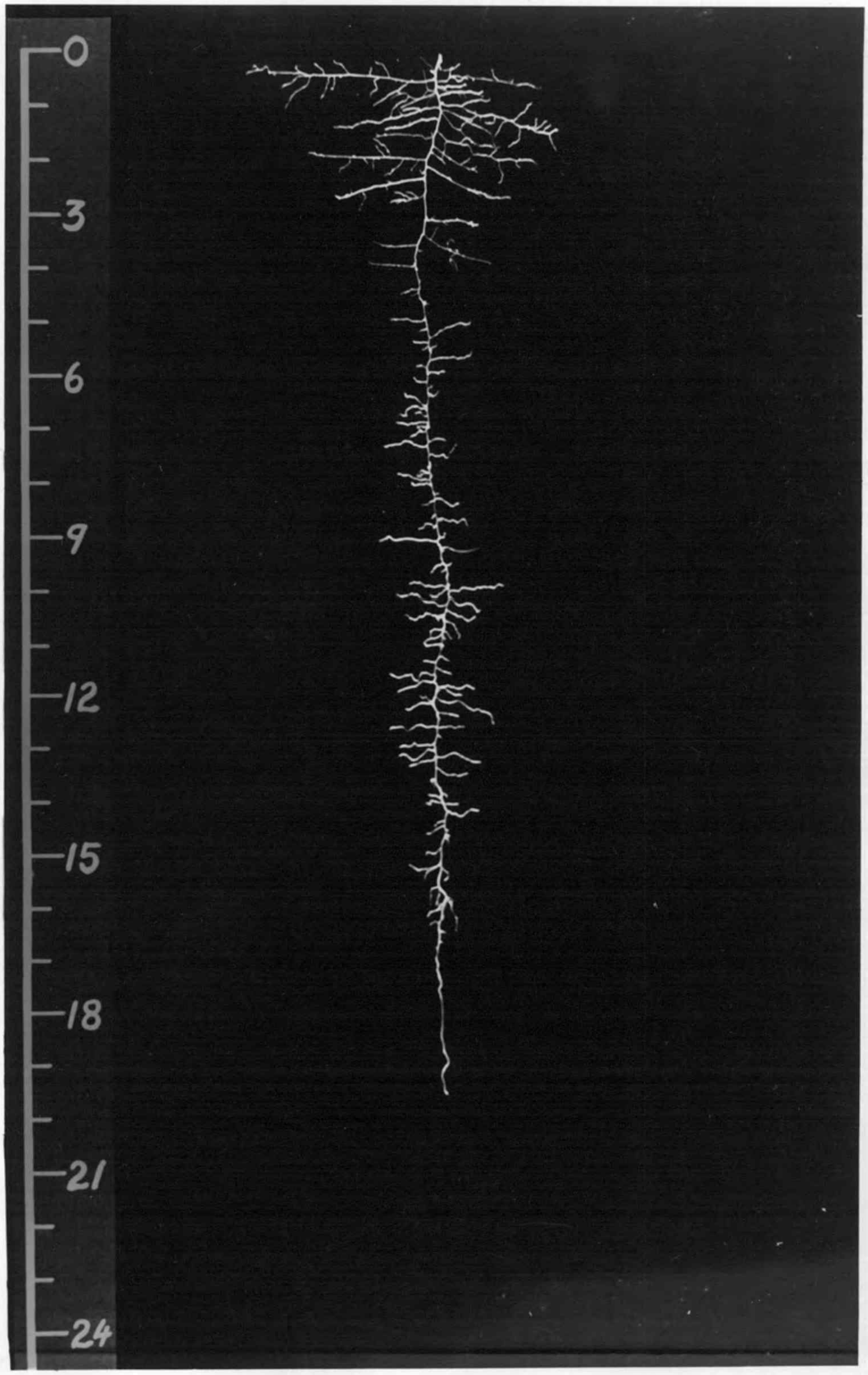


Plate XXII

WHITE CLOVER
Root Development at 171 Days from Time of Seeding in

Melbourne Clay



White Clover at Early Bloom Stage in Chehalis Clay Loam

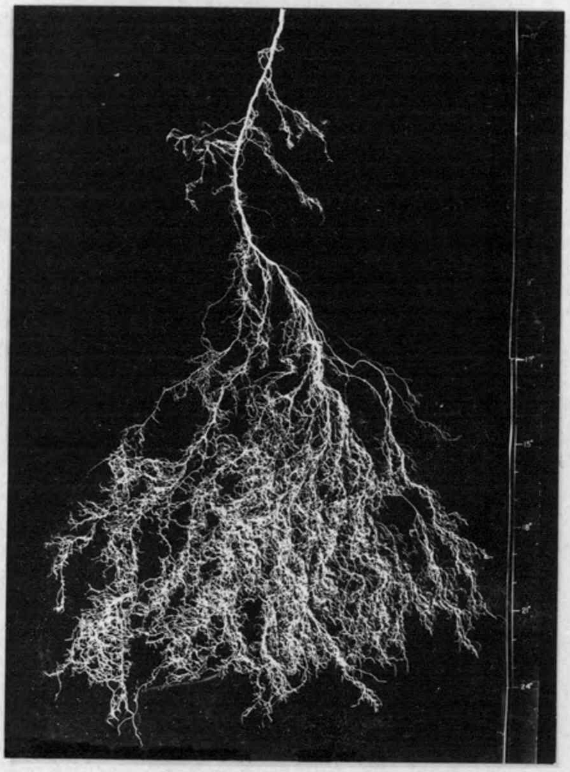
Spring planted white clover observed in early August, 86 days from planting,was similar in performance to that of alsike clover, (Plate XXIII). The taproot at this time was prominent to a depth of 11 inches at which point it became lost in numerous large laterals. Little or no branching occurred in the top 9 inches; that which was present appeared to be in a dry corkey condition. Numerous large laterals were borne below the nine inch level and many of them penetrated the soil to a greater depth than the taproot. These laterals were clothed with numerous second order roots. Some fourth order roots were present but they were very short and small. The concentrated zone of feeding roots was found in the lower layers of soil. Below a depth of 12 inches the root system of white clover appears to be as fibrous as those of grasses. This abundant lateral growth, as in alsike clover, was controlled principally by moisture relationships.

Plate XXIII

WHITE CLOVER

Root Development at Early Bloom Stage in

Chehalis Clay Loam



3. Ladino clover (Trifolium repens latum)

The data from the five observations made on Ladino clover are given in Tables X, XI, XII, and XIII, and Plates XXIV to XXXII. Observations on the root systems of this vigorously growing plant at 28, 56, and 84 days showed less influence from soil types than in the case of alsike and white clover. At the latter observations the larger weight of roots and tops and greater plant development signify that the effect of higher fertility possessed by the Chehalis and Willamette soils was becoming evident. At 112 days from date of seeding as in the previous observations, the pattern of root growth was similar in all soil types.

At the last observation, 171 days from seeding, (Tables X, XI, and XII, and Plates XXX, XXXI, and XXXII), the effect of soil type was apparent. This was indicated by the weight of tops and roots, diameter of root system and the number and spread of laterals, which were higher in all cases in the Chehalis and Willamette soils.

Data on the lateral root development, as determined in connection with this study, are summarized in Table XIII. As in similar observations made on the other crops, lateral development was greater and more extensive in the Chehalis soil. Branching of the taproot of plants grown in Willamette clay, although not extensive, was greater than that which occurred in the Melbourne soil. Such results are caused by the differnce in fertility which exists between these two soils.

The effect of compact zones of soil on lateral development of Ladino clover were easily seen as with the other crops studied. From 6 to 12 inches in Willamette clay the number and spread of laterals have both been reduced. In Melbourne clay from 6 to 8 inches, lateral spread was decreased. As the taproot left the tillage pan in these soils, lateral spread increased. This was due to the less dense condition existing below these zones of compaction, (Tables XXIII and XXIV). The zones of compaction as shown in these latter tables correspond with those regions in which the number and spread of laterals has been reduced, (Table XIII and Plates XXX, XXXI, and XXXII).

Table X

Root and Top Development of Ladino Clover
Plants at Various Ages

Chehalis Clay Loam

Month of observation	Nov.	Dec.	Jan.	Feb.	Apr.
Age (days from seeding)	28	56	84	112	171
Leaf development	coty-ledon	first	second	third	stolons
Root penetration (inches)	2.5	3.25	4.25	5.6	25
*Weight of root (grams)	.0005	.0008	.0022	.0040	.1200
Depth of laterals roots (inches)	1.5	1.25	2.5	4.	21
Diameter of root system (inches)	1	1	2.5	4.5	9
Number of lateral roots	5	11	15	29	115
Length of top (inches)	.5	.5	.5	.75	3
*Weight of top (grams)	.0006	.0011	.0026	.0047	.1776
Root development (order)	first	first	second	second	third
Position of nodule formation		tap-root	tap-root	first order	second order

*Oven-dry basis 105° C

All results based on average of three or more plants

Table XI

Root and Top Development of Ladino Clover Plants at Various Ages

Willamette Clay

Month of observation	Nov.	Dec.	Jan.	Feb.	Apr.
Age (days from seeding)	28	56	84	112	171
Leaf development	coty-ledon	first	second	third	stolon
Root penetration (inches)	2.5	3	4.5	8.7	24
*Weight of root (grams)	.0006	.0010	.0023	.0042	.0630
Depth of lateral roots (inches)	1	1.5	2.25	5	20
Diameter of root system (inches)	.5	1.2	2	4	8
Number of lateral roots	4	11	17	40	143
Length of top (inches)	.5	.5	.5	1	3
*Weight of top (grams)	.0005	.0013	.0023	.0052	.1126
Root development (order)	first	first	second	second	third
Position of nodule formation		tap-root	first order	first order	second order

*Oven-dry basis 105° C

All results based on average of three or more plants

Table XII

Root and Top Development of Ladino Clover Plants at Various Ages

Melbourne Clay

Month of observation	Nov.	Dec.	Jan.	Feb.	Apr.
Age (days from seeding)	28	56	84	112	171
Leaf development	coty-ledon	first	first	third	num-erous
Root penetration (inches)	2.4	3	4	5.5	25
*Weight of root (grams)	.0005	.0007	.0012	.0031	.0288
Depth of lateral roots (inches)	.75	1.5	2.	2.75	17
Diameter of root systems (inches)	1.2	1.5	2	3.25	7
Number of lateral roots	8	8	13	23	114
Length of top (inches)	.5	.5	.5	1	2
*Weight of top (grams)	.0005	.0007	.0015	.0029	.0375
Root development (order)	first	first	second	second	third
Position of nodule formation	tap-root	tap-root	tap-root	first order	second order

*Oven-dry basis 105° C

All results based on average of three or more plants

Table XIII

Number of Lateral Roots per Inch Section of Taproot of
LADINO CLOVER
at Different Depths and at Successive Ages in Three Soil Types

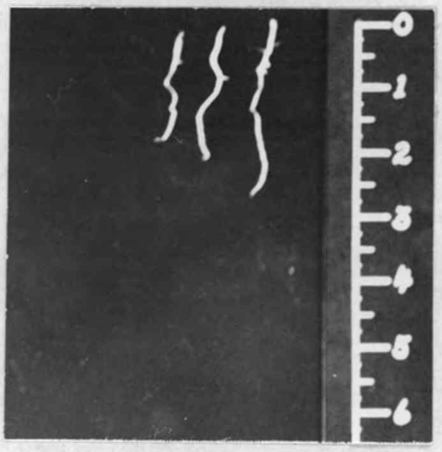
Depth of Section of taproot	SOIL TYPE											
	Chehalis Clay Loam				Willamette Clay				Melbourne Clay			
	Days from Seeding				Days from Seeding				Days from Seeding			
	56	84	112	171	56	84	112	171	56	84	112	171
inches												
0-1	9	9	11	11	8	9	10	16	7	10	11	18
1-2	2	4	7	8	3	8	8	12	1	4	9	11
2-3		3	5	7		2	8	11			4	8
3-4			5	9			7	8			1	5
4-5				8			6	10				7
5-6				7			2	9				7
6-7				8				9				9
7-8				9				6				11
8-9				8				6				8
9-10				7				5				11
10-11				8				5				8
11-12				7				6				6
12-13				7				9				5
13-14				6				10				6
14-15				6				11				3
15-16				7				9				2
16-17				4				10				1
17-18				3				9				
18-19								4				
19-20								3				

Plate XXIV

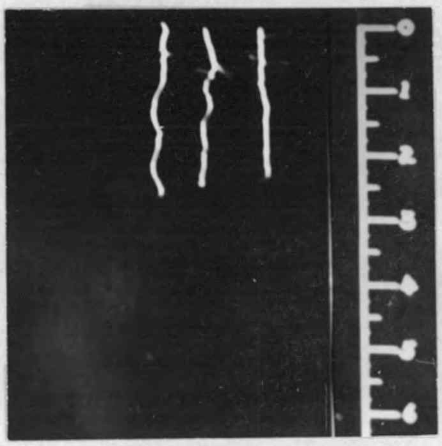
LADINO CLOVER

Root Development at 28 Days from Time of Seeding on

Chehalis Clay Loam



Willamette Clay



Melbourne Clay

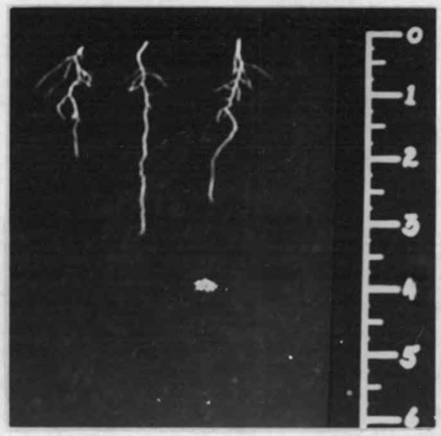
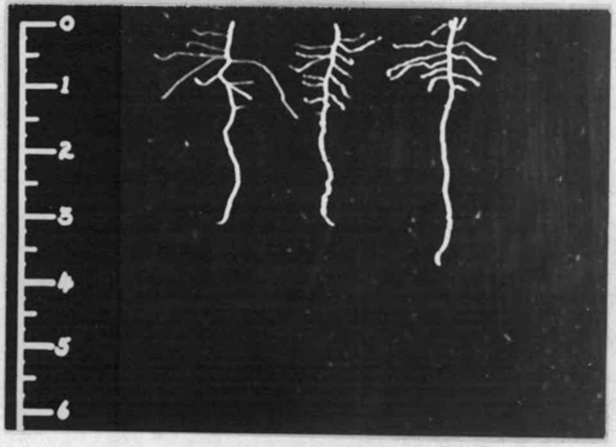


Plate XXV

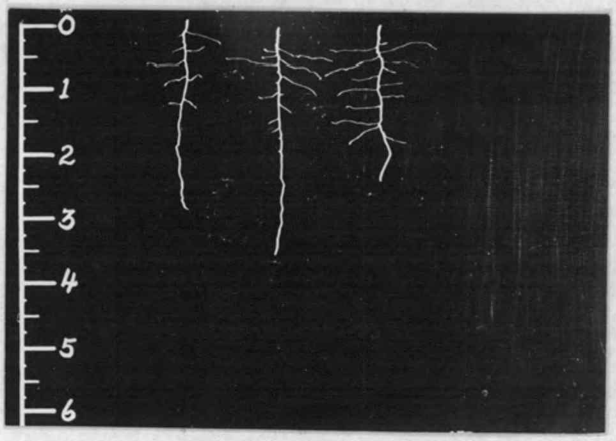
LADINO CLOVER

Root Development at 56 Days from Time of Seeding on

Chehalis Clay Loam



Willamette Clay



Melbourne Clay

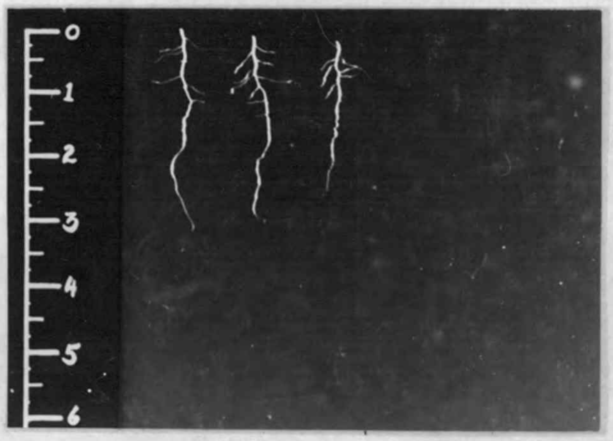
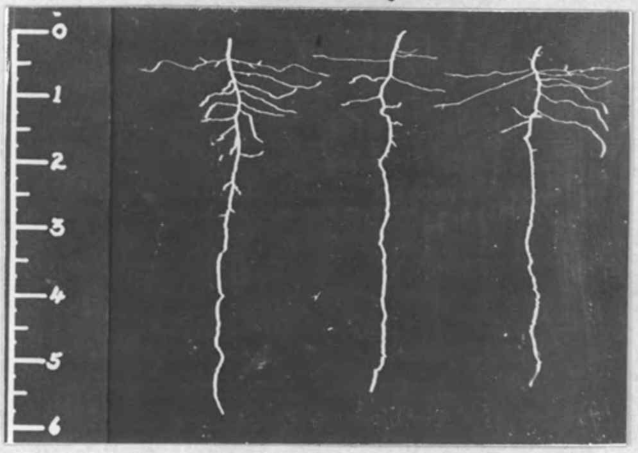


Plate XXVI

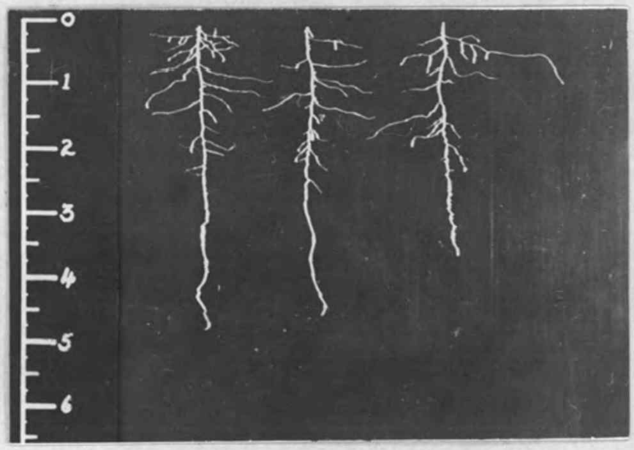
LADINO CLOVER

Root Development at 84 Days from Time of Seeding on

Chehalis Clay Loam



Willamette Clay



Melbourne Clay

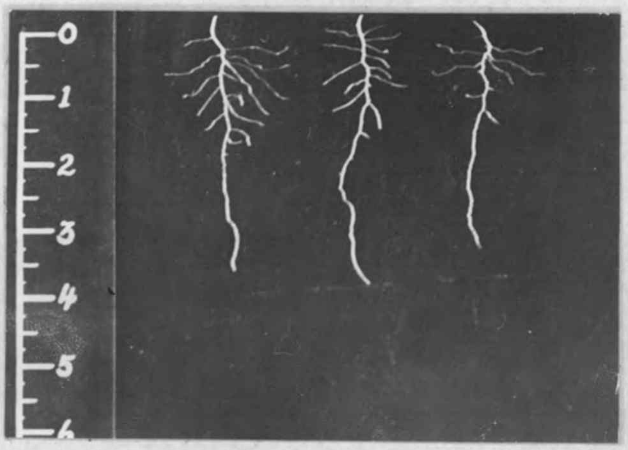


Plate XXVII

LADINO CLOVER

Root Development at 112 Days from Time of Seeding on

Chehalis Clay Loam

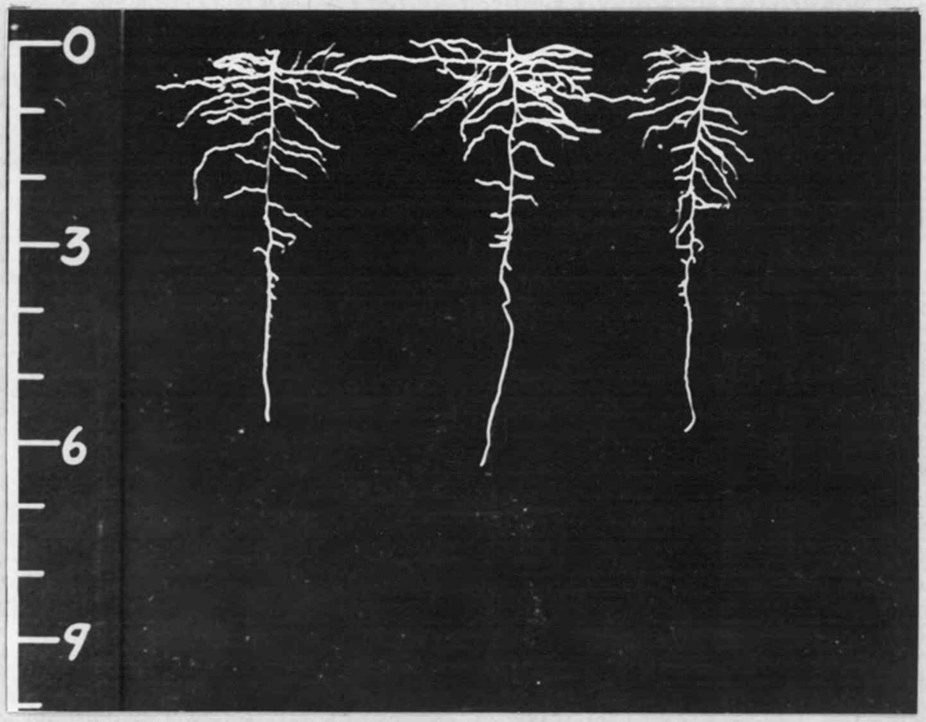


Plate XXVIII

LADINO CLOVER

Root Development at 112 Days from Time of Seeding on

Willamette Clay

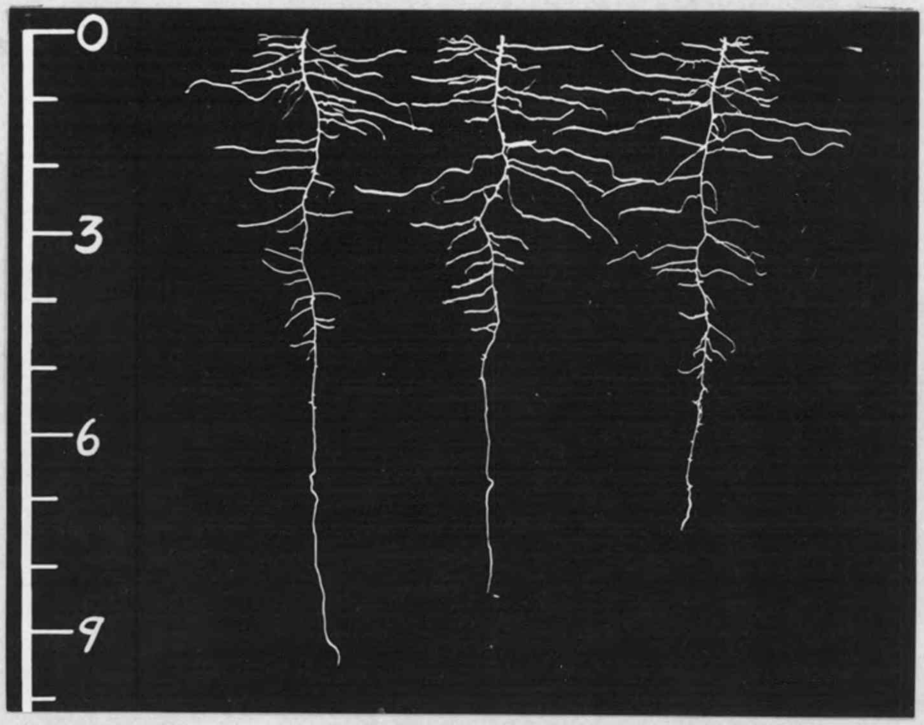


Plate XXIX

LADINO CLOVER

Root Development at 112 Days from Time of Seeding on

Melbourne Clay

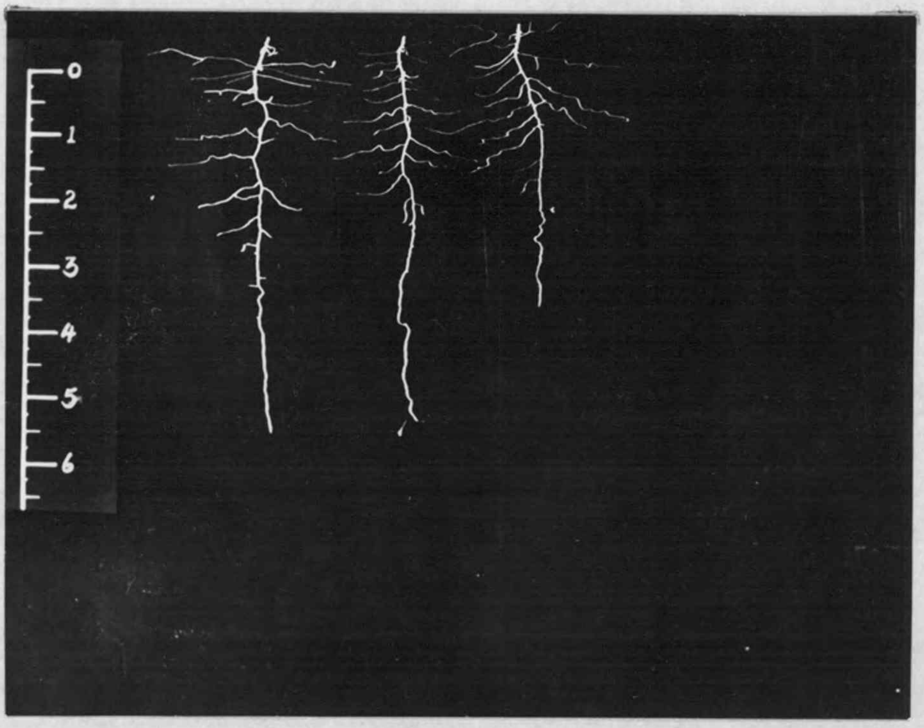


Plate XXX

LADINO CLOVER
Root Development at 171 Days from Time of Seeding in

Chehalis Clay Loam

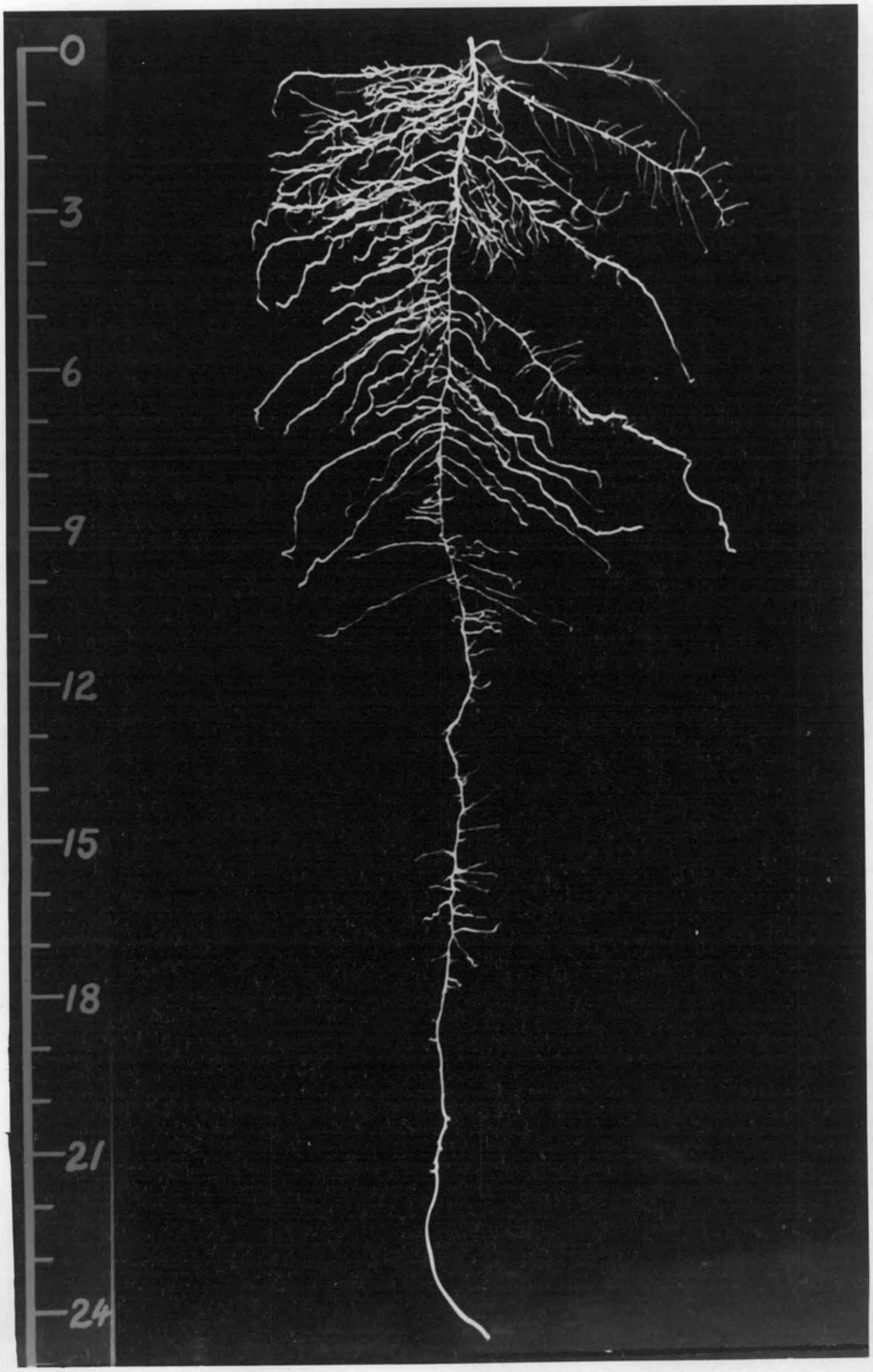


Plate XXXI

LADINO CLOVER
Root Development at 171 Days from Time of Seeding in

Willamette Clay

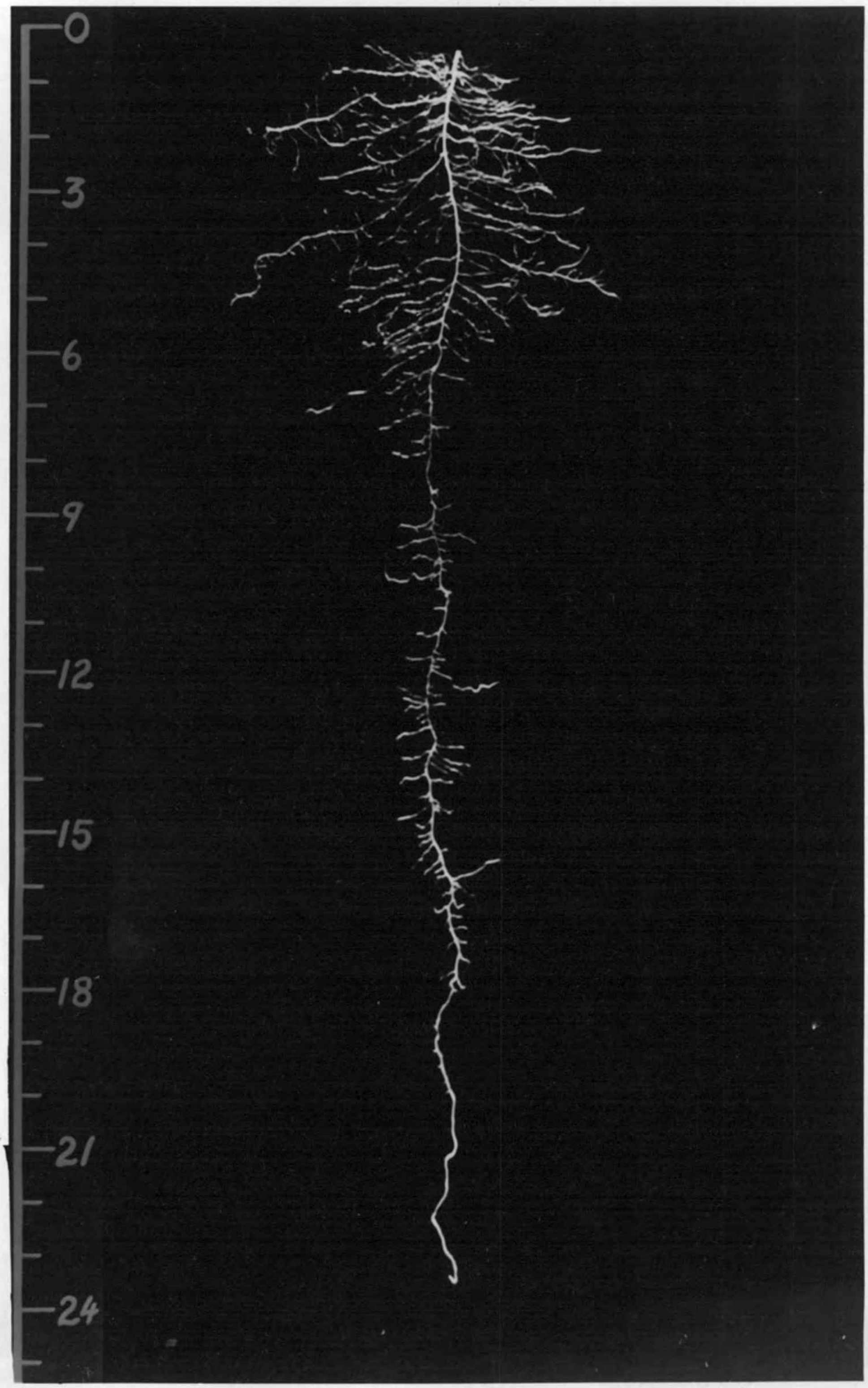
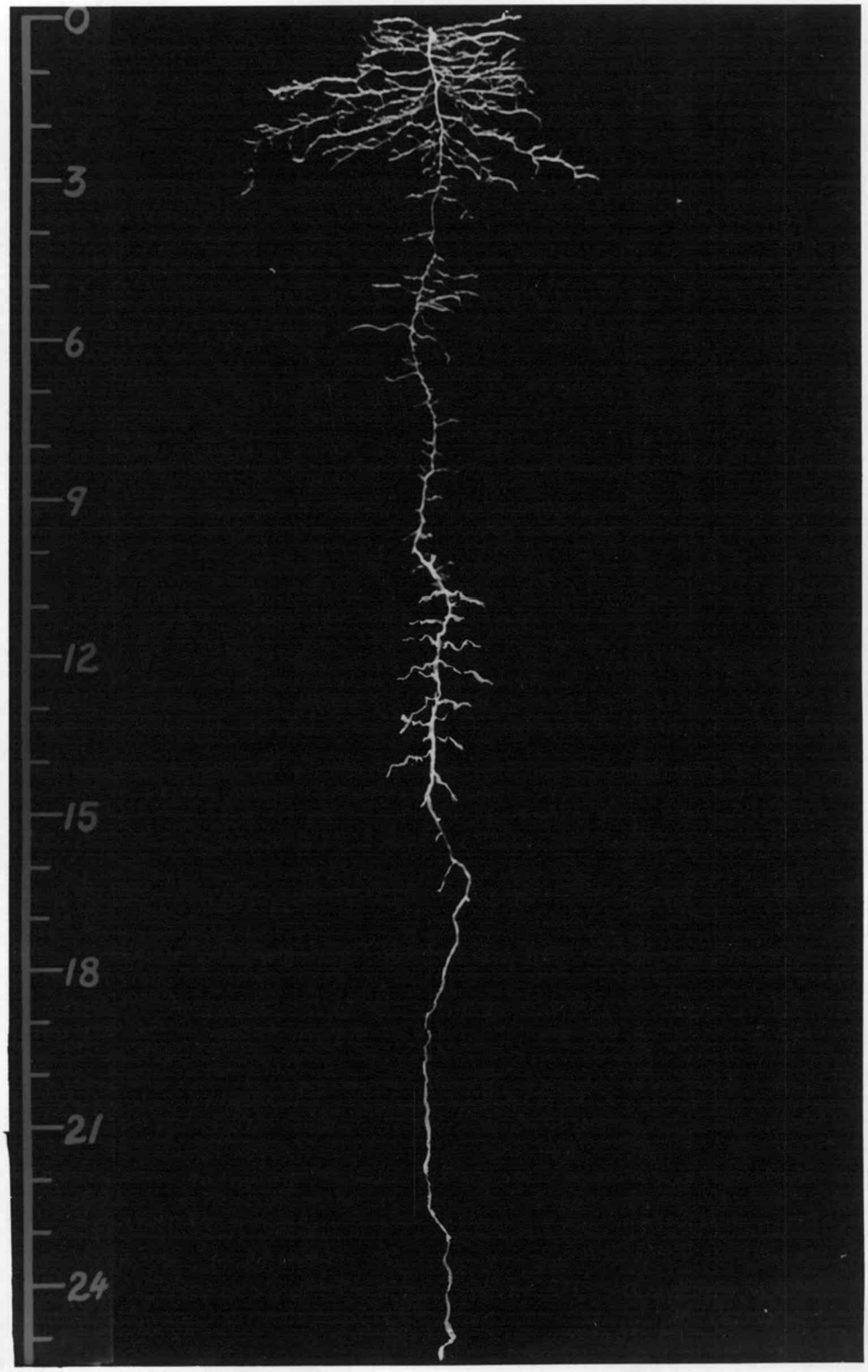


Plate XXXII

LADINO CLOVER
Root Development at 171 Days from Time of Seeding in

Melbourne Clay



Ladino Clover at Early Bloom Stage in Chehalis Clay Loam

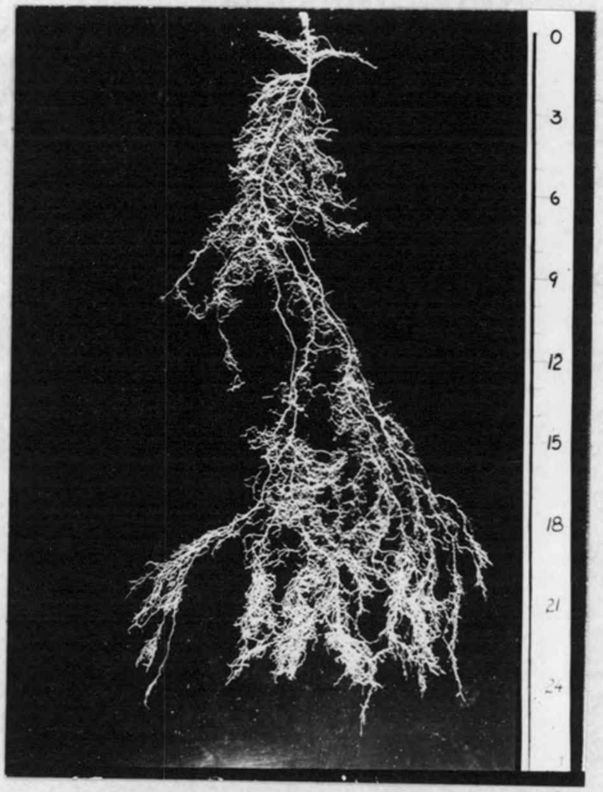
Spring seeded Ladino clover observed in August at the early bloom stage grew in a similar pattern to those of alsike and white clover. At this time the root system consisted of a taproot clothed with numerous laterals, some of which penetrated the soil to a depth greater than that of the taproot. The taproot decreased rapidly in diameter for the first few inches after which it remained fairly constant throughout its length. Although there appears to be two feeding zones this is not actually the case. Those roots concentrated in the upper portion of the root system were distorted and corky and of little importance as absorbers of nutrients. The laterals were profusely branched in the lower portion, (15 to 24 inches), and were very active as nutrient absorbers. The feeding zone of this crop as in alsike and white clover is forced to go deeper because the surface soil becomes depleted of moisture in the summer months when little precipitation falls, (Table I).

Plate XXXIII

LADINO CLOVER

Root Development at Early Bloom Stage in

Chehalis Clay Loam



4. Strawberry clover (Trifolium fragiferum)

The results of the observations made on strawberry clover are summarized in Tables XIV, XV, XVI, and XVII, and Plates XXXIV to XL. The taproot was the dominant feature of the root system of those plants observed at 84 and 112 days from date of seeding. It penetrated directly downward and was only sparsely branched. The effect of soil types, although small, was beginning to appear at 112 days. The larger weight of plants, spread of laterals, and leaf development of plants growing in Chehalis clay loam indicate this.

As the plants grew older the effect of soil type on root growth became more pronounced.

The ratio of roots to tops in both the Chehalis and Willamette soils was greater than one, whereas, the ratio on the Melbourne soil was less than one. This was probably due to the deficient supply of nutrients in the latter soil, (Table XXIV).

A summary of lateral root development is presented in Table XVII. Review of this table indicates that as the crop matures the number of laterals for a given section of taproot and the depth of lateral root formation increases with the age of the plant. Plate XXXVIII shows that plants growing in Chehalis clay loam contained numerous laterals, many of which penetrated to a depth as great or greater than that of the taproot. These laterals were covered with numerous second order roots while those plants growing in the Willamette and Melbourne soils were very few. Such vigorous root systems of those plants in the Chehalis soil are probably due to the superior fertility as shown in Table XXII.

Root penetration and growth in general was less in strawberry clover than in any clovers studied.

Table XIV

Root and Top Development of Strawberry Clover Plants at Various Ages

Chehalis Clay Loam

Month of observation	Jan.	Feb.	Apr.
Age(days from seeding)	84	112	171
Leaf development	first	third	numerous
Root penetration (inches)	3.25	4.25	10.5
*Weight of root (grams)	.0021	.0043	.0700
Depth of lateral roots (inches)	1.25	2.5	6
Diameter of root system (inches)	2.5	2.75	11
Number of lateral roots	9	17	63
Length of top (inches)	.75	1	2.5
*Weight of top (grams)	.0030	.0057	.0760
Root development (order)	first	first	second
Position of nodule formation	tap-root	first order	second order

*Oven-dry basis 105° C

All results based on average of three or more plants

Table XV

Root and Top Development of Strawberry Clover
Plants at Various Ages

Willamette Clay

Month of observation	Jan.	Feb.	Apr.
Age(days from seeding)	84	112	178
Leaf development	first	third	numerous
Root penetration (inches)	3.25	4	10.5
*Weight of root (grams)	.0017	.0034	.0266
Depth of lateral roots (inches)	1.75	2.5	9
Diameter of root system (inches)	1.75	2	6
Number of lateral roots	8	12	69
Length of top (inches)	.5	1	1
*Weight of top (grams)	.0019	.0047	.0283
Root development (order)	first	first	second
Position of nodule formation	tap-root	tap-root	first order

*Oven-dry basis 105° C

All results based on average of three or more plants

Table XVI

Root and Top Development of Strawberry Clover Plants at Various Ages

Melbourne Clay

Month of observation	Jan.	Feb.	Apr.
Age(days from seeding)	84	112	178
Leaf development	first	second	numerous
Root penetration (inches)	3.5	5	10.5
*Weight of root (grams)	.0016	.0026	.0243
Depth of lateral roots (inches)	1.75	2.25	8
Diameter of root system (inches)	1.75	2	5
Number of lateral roots	8	13	52
Length of top (inches)	.75	.75	1.5
*Weight of top (grams)	.0017	.0029	.0223
Root development (order)	first	first	second
Position of nodule formation	tap-root	tap-root	first order

*Oven-dry basis 105° C

All results based on average of three or more plants

Table XVII

Number of Lateral Roots per Inch Sections of Taproot of

STRAWBERRY CLOVER

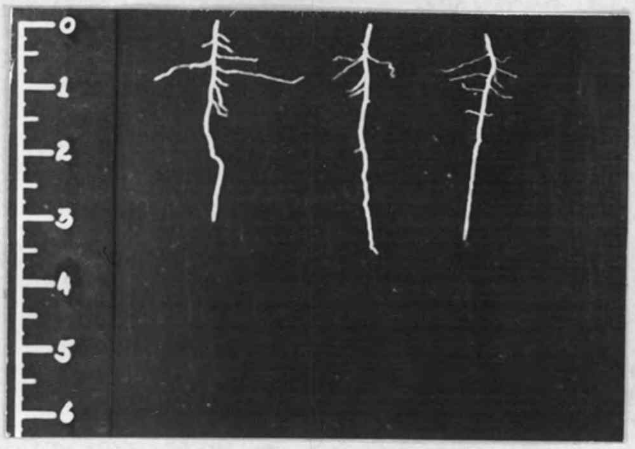
at Different Depths and at Successive Ages in Three Soil Types

Depth of Section of taproot	SOIL TYPE								
	Chehalis Clay Loam			Willamette Clay			Melbourne Clay		
	Days from Seeding			Days from Seeding			Days from Seeding		
	84	112	171	84	112	171	84	112	171
1"-2"	7	8	25	3	6	11	4	7	12
2"-3"	2	6	13	3	5	10	3	4	8
3"-4"		2	8		1	6		2	9
4"-5"			9			7			2
5"-6"			9			10			1
6"-7"			5			10			6
7"-8"						6			8
8"-9"						5			10
9"-10"						3			
10"-11"									

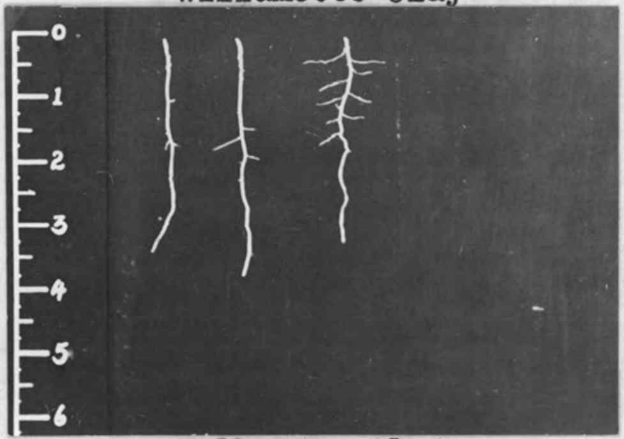
STRAWBERRY CLOVER

Root Development at 84 Days from Time of Seeding in

Chehalis Clay Loam



Willamette Clay



Melbourne Clay

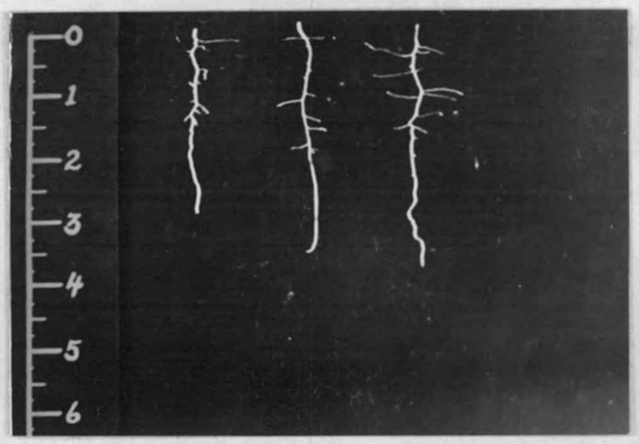


Plate XXXV

STRAWBERRY CLOVER

Root Development at 112 Days from Time of Seeding in

Chehalis Clay Loam

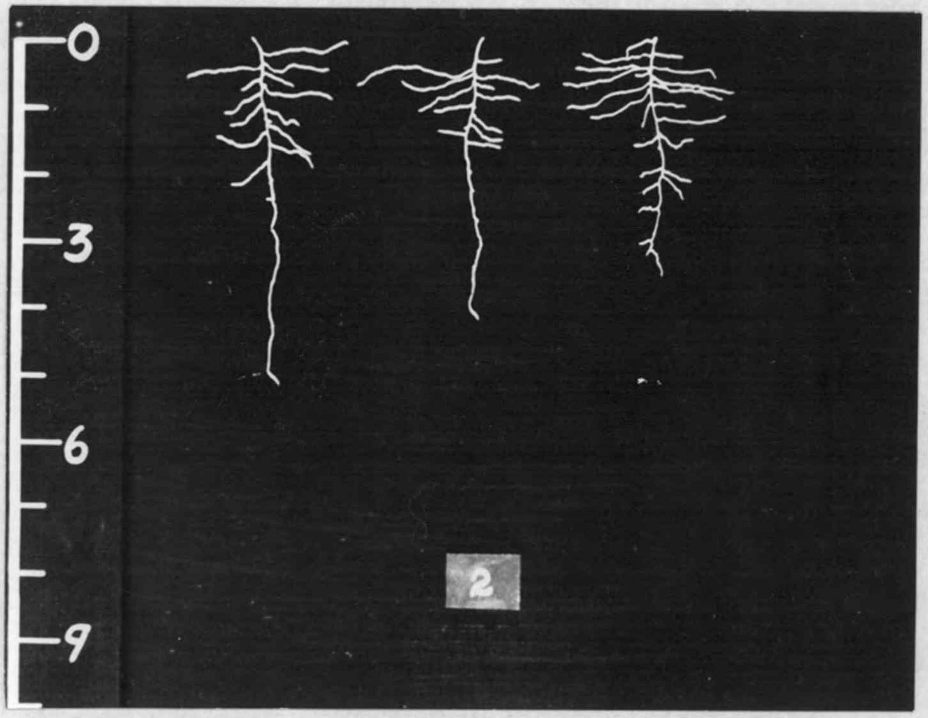


Plate XXXVI

STRAWBERRY CLOVER

Root Development at 112 Days from Time of Seeding in

Willamette Clay

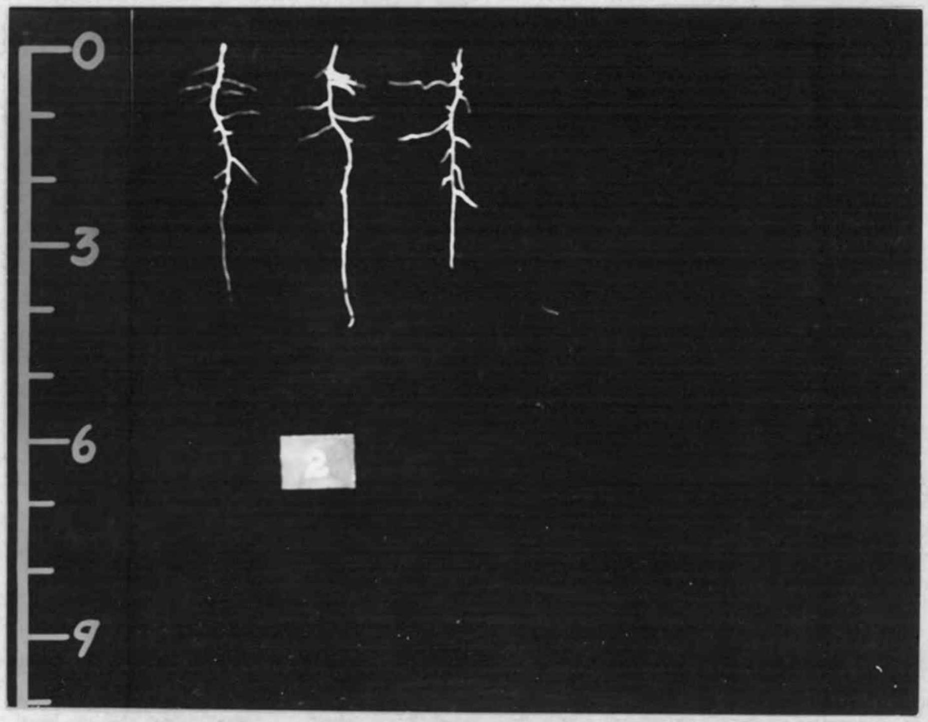


Plate XXXVII

STRAWBERRY CLOVER

Root Development at 112 Days from Time of Seeding in

Melbourne Clay

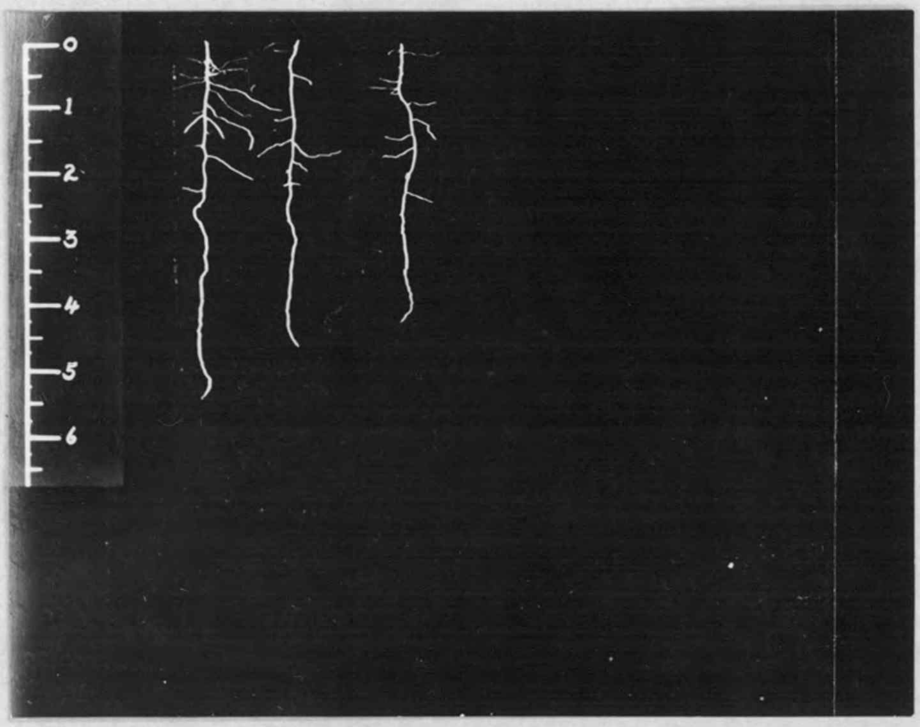


Plate XXXVIII

STRAWBERRY CLOVER
Root Development at 171 Days from Time of Seeding in

Chehalis Clay Loam

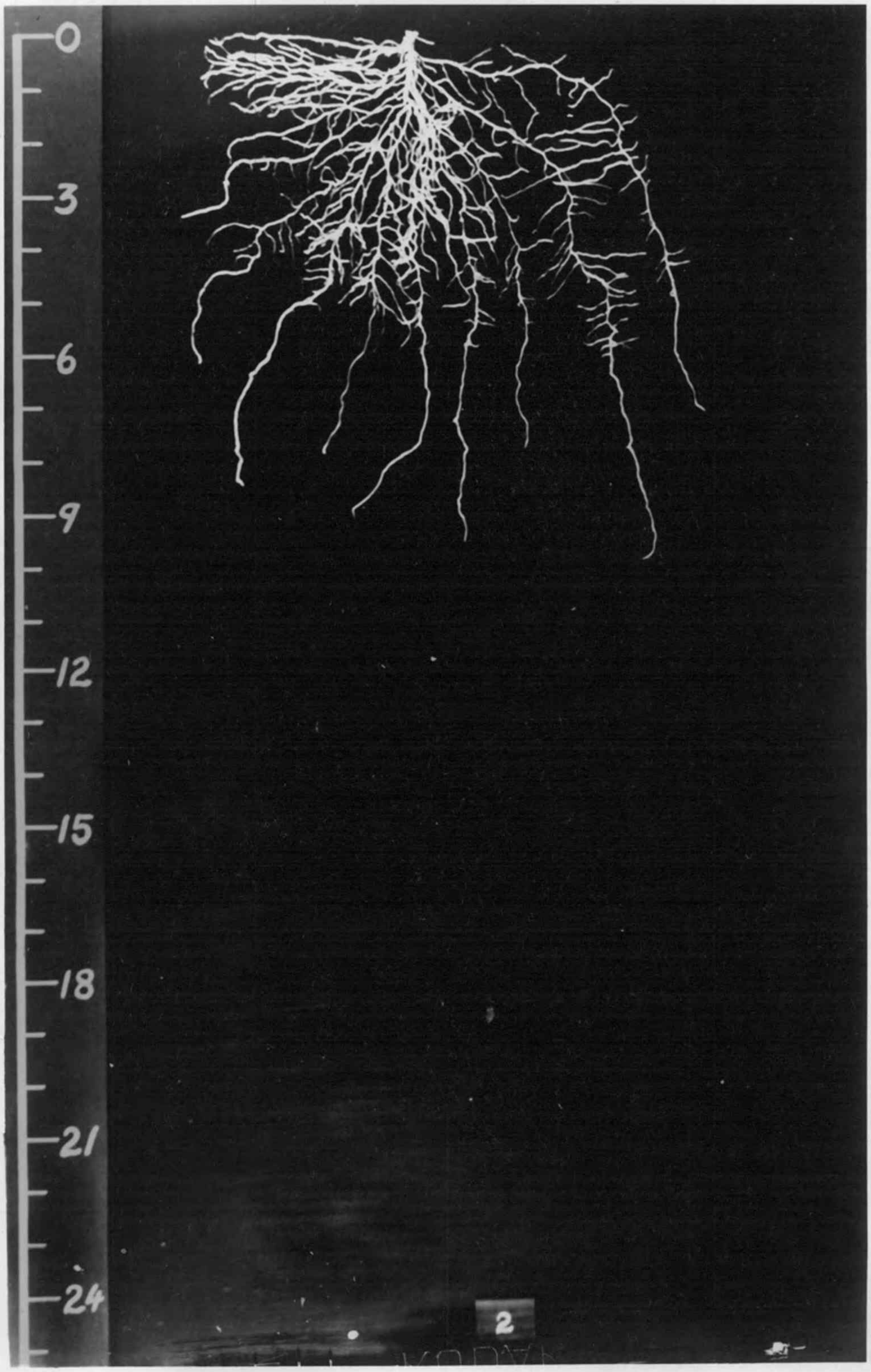


Plate XXXIX

STRAWBERRY CLOVER
Root Development at 171 Days from Time of Seeding in

Willamette Clay

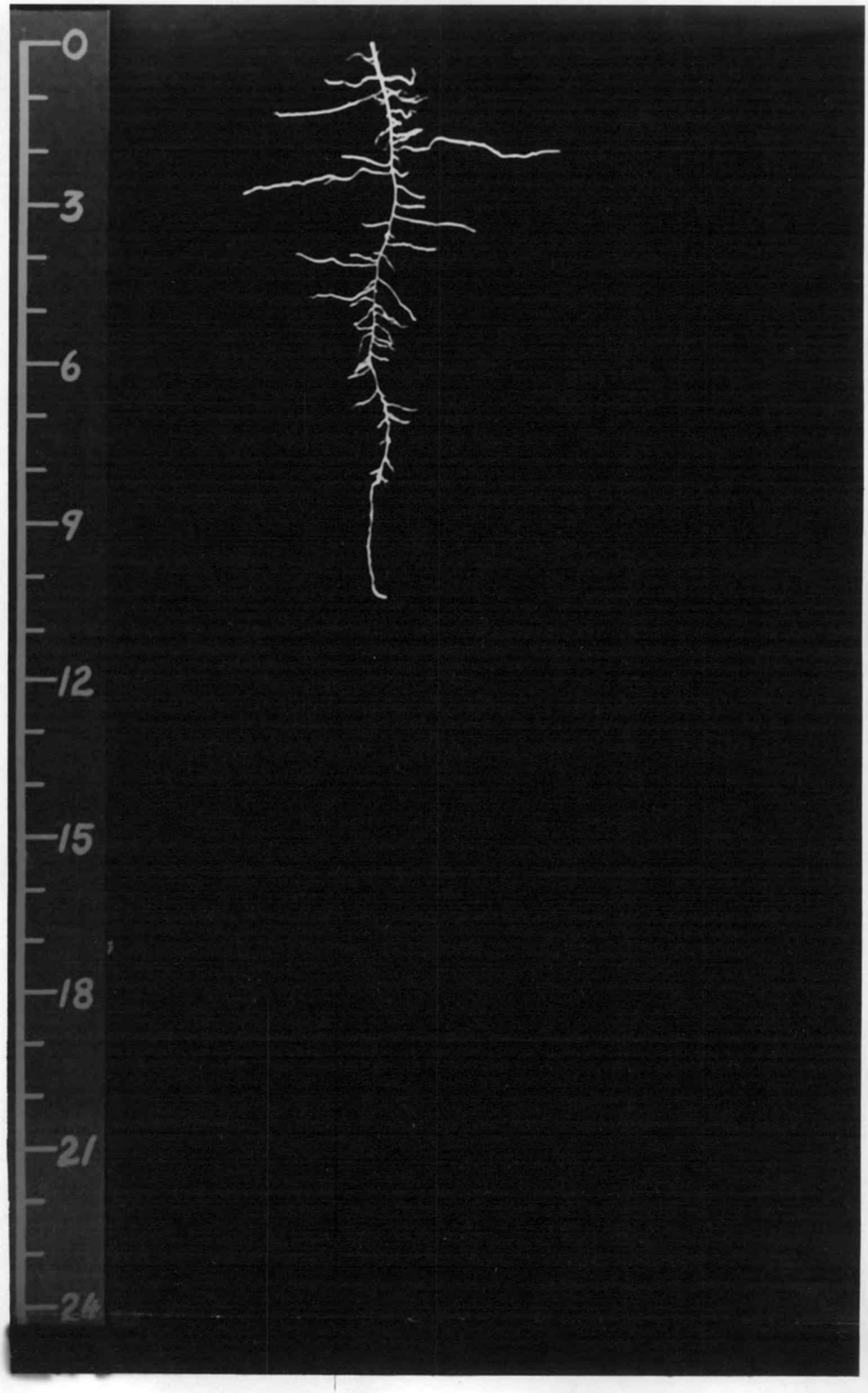
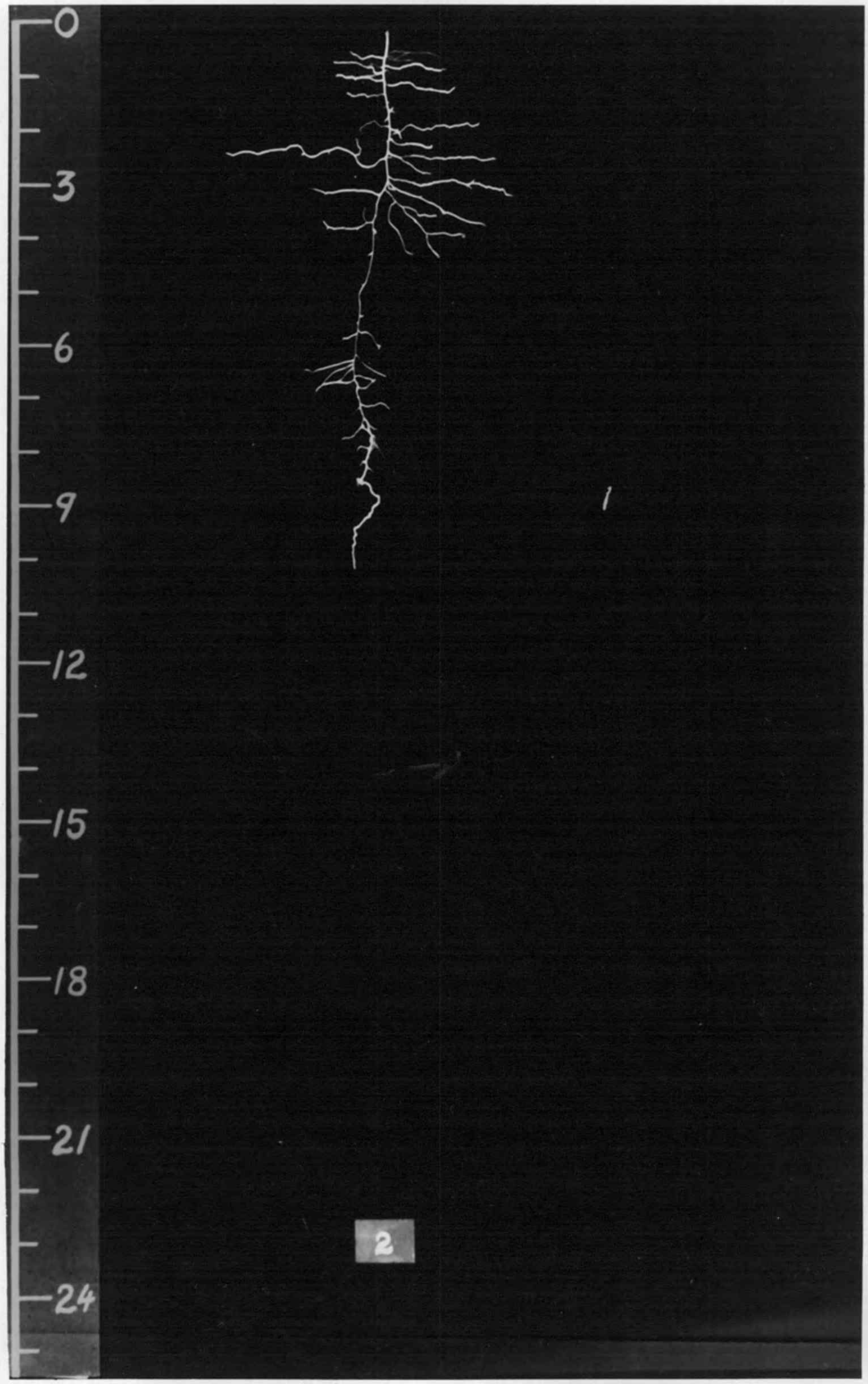


Plate XL

STRAWBERRY CLOVER
Root Development at 171 Days from Time of Seeding in

Melbourne Clay



Strawberry Clover at Maturity in Chehalis Clay Loam

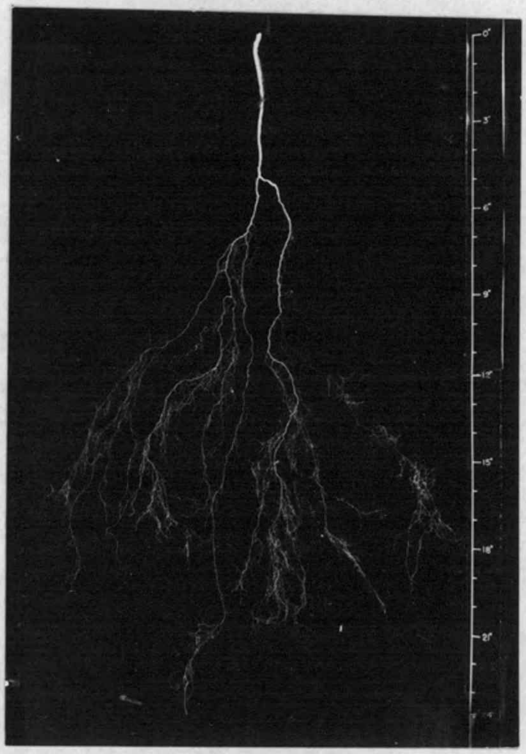
A planting of strawberry clover made in the spring of 1940 in Chehalis clay loam made more rapid root development than plantings made in the fall in this soil. As shown by Plate XLI, the root system of this plant consisted of a taproot sparsely branched to a depth of nine inches. At this point numerous large laterals were developed. These penetrated to a depth greater than that of the taproot and were clothed with a large number of second order roots. The feeding zone was principally below a depth of 12 inches. The ratio of roots to the tops was 1 to 2.5 and numerous third order roots were present.

Plate XLI

STRAWBERRY CLOVER

Root Development at Maturity in

Chehalis Clay Loam



B. <u>Crops Observed in the Summer Months</u>:

The following is a record of observations made on those crops that produced at least fair stands during the summer months.

1. <u>Red clover</u> (Trifolium pratense)

No observations were made in the Willamette soil type because of failure to secure a stand. The results obtained from the study of red clover are summarized in Table XVIII and Plates XLII and XLIII. These observations indicate that red clover is a moderately deep feeding perennial with a comparatively fine profusely branched root system. Root development in Chehalis clay loam was similar to that of plants growing in the Melbourne soil, (Plate XLII).

The superior qualities of the Chehalis soil (Table XXII) are reflected in the development of the crop thereon. Red clover growing in Chehalis produced vigorous root systems, greater plant weight, had advanced more than those on the Melbourne soil.

The weight of the tops in the Chehalis soil was greater than the weight of the roots in both observations, whereas, in the Melbourne soil the weight of top growth was only slightly greater at the 113-day observation, and less than the weight of the roots in the 195-day observation. This was probably due to a combination of the low amount of moisture and available nutrients.

In contrast to the first observations made on this crop later observations showed that the feeding zone of plants growing in both soils had moved from the lower horizons to the surface six to eight inches of soil. This complete reverse in feeding zones (Plates XLII and XLIII) was due to a renewal of soil moisture by rains previous to these observations. Roots below the 8 inch level appeared dry and corkey and many of the laterals were disintegrating. This decrease of the number of feeding roots in the lower horizons may be accounted for by the plant tendency to send out new feeding roots in those zones where moisture, nutrients, and air are conducive to root growth.

Table XVIII

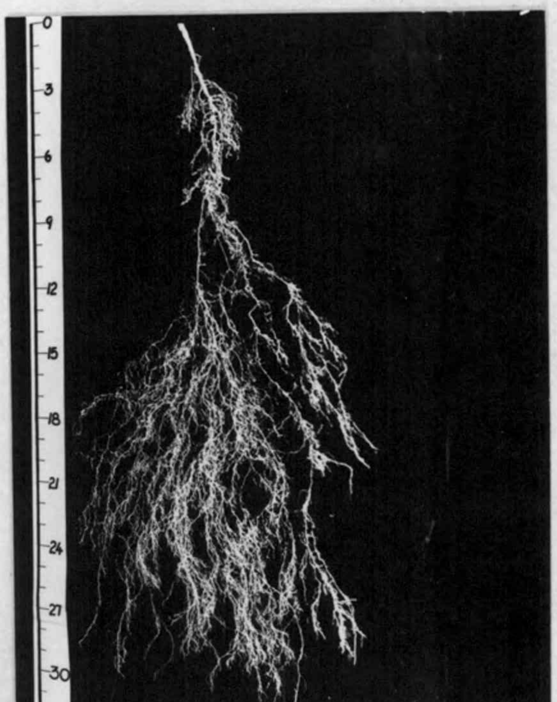
Root and Top Development of Red Clover
Plants at Various Ages

Soil Type	Chehalis Clay Loam		Melbourne Clay	
Month of observation	Aug.	Nov.	Sept.	Nov.
Age (days from seeding	93	173	113	195
Root penetration (inches)	33	48	23	33
*Weight of roots (grams)	1.55	3.00	.275	1.07
Depth at which majority of feeder roots are located (inches)	12-29	0-9	9-16	0-6
Diameter of root system (inches)	12	14	10	14
Length of top growth (inches)	12	14	3	4
Weight of top (grams)	4.08	5.15	.65	.99

Plate XLII

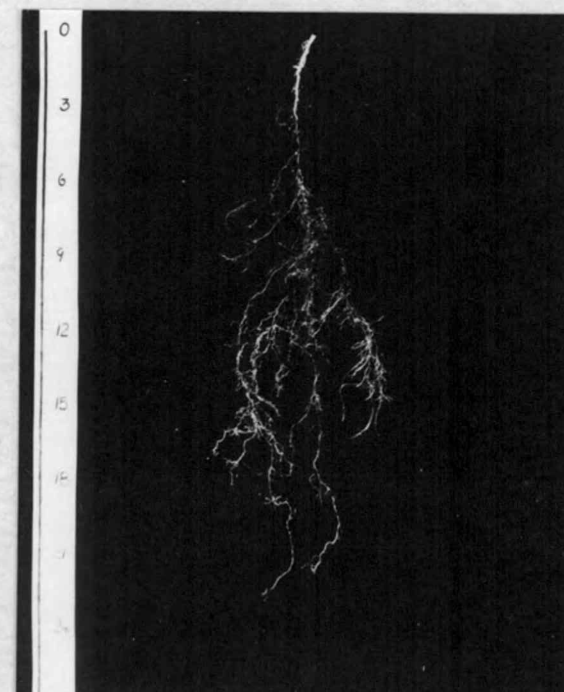
Root Development of Red Clover in

Chehalis Clay Loam



93 days from date of seeding

Melbourne Clay

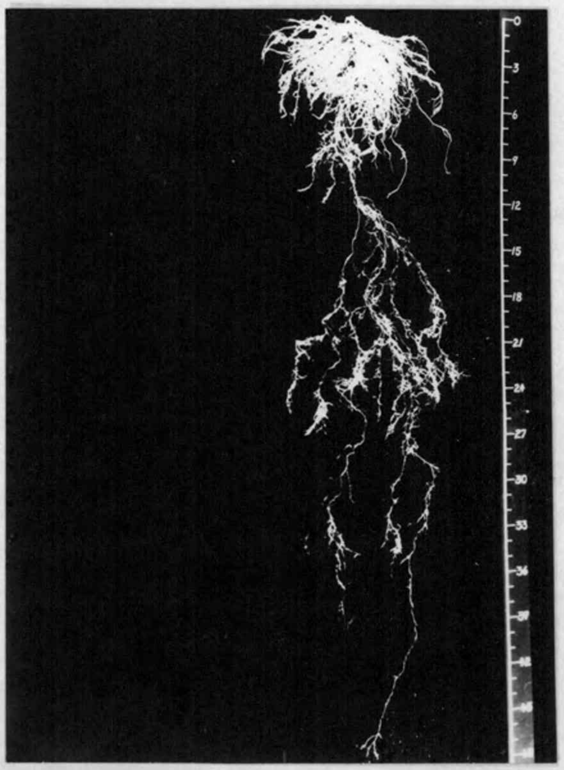


113 days from date of seeding

Plate XLIII

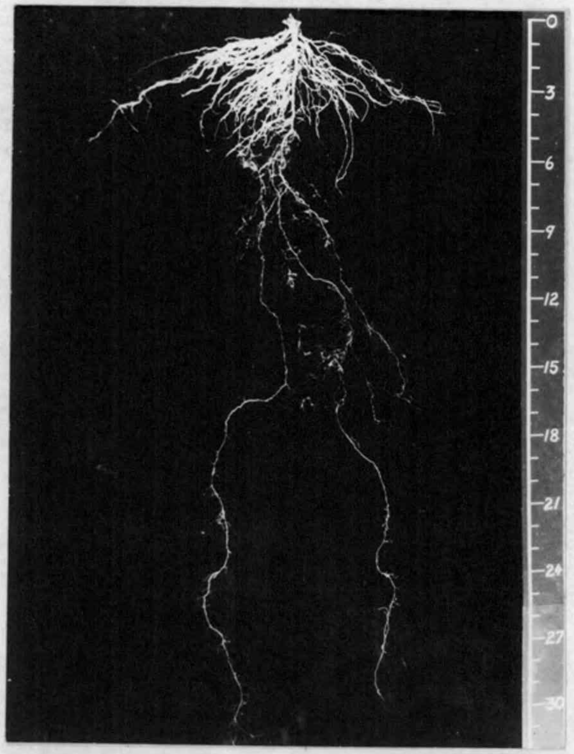
Root Development of Red Clover in

Chehalis Clay Loam



173 days from date of seeding

Melbourne Clay



195 days from date of seeding

2. <u>Lotus corniculatus</u>

No observations were made in the Willamette soil because of failure to secure a stand.

A summary of the results obtained from observations made in the Chehalis and Melbourne soils is presented in Table XIX and Plates XLIV and XLV.

The superiority of the root systems grown in Chehalis clay loam is very pronounced as shown by the measured factors, (Table XIX). The root systems of plants growing in Chehalis, although the plants were 38 days younger, were profusely branched. It penetrated to a depth of 51 inches as compared to 40 inches in the Melbourne soil. Root penetration was limited by bed rock which occurred at a depth of approximately 36 inches, (Table XXIV).

The zone of feeding roots was located in the lower portion of the root systems in both soils.

The root-top ratio of plants growing in the Chehalis soil was greater than 2 as compared to a ratio of 1.2 for the Melbourne soil.

The lack of extensive root and top development in the Melbourne soil was probably due to three factors, lack of available moisture, plant nutrients, and the shallowness of the soil.

Table XIX

Root and Top Development of Lotus
Plants at Various Ages

Soil Type	Chehalis Clay Loam	Melbourne Clay
Month of observation	August	September
Aage(days from seeding)	91	129
Root penetration (inches)	51	40
*Weight of roots (grams)	2.42	.36
Depth at which majority of feeder roots are located (inches)	15-48	0-40
Diameter of root system (inches)	16	12
Length of top growth (inches)	12	3.5
Weight of top * (grams)	5.08	.43

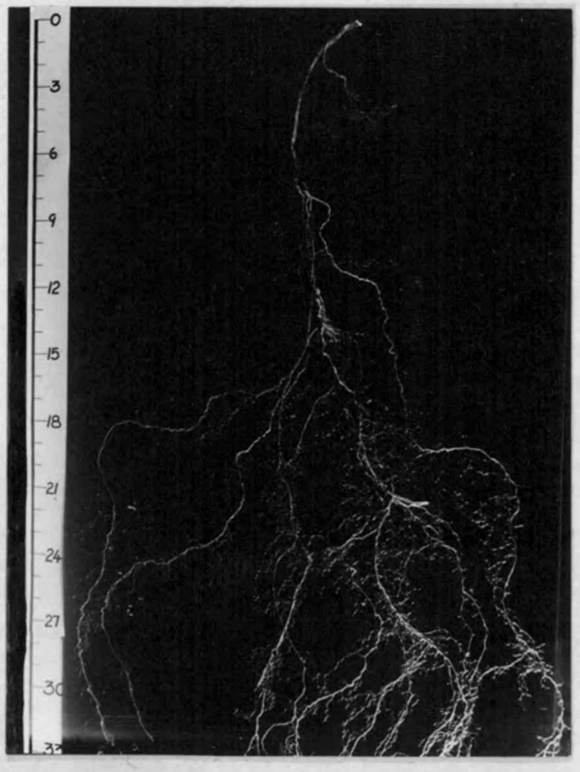
*Oven-dry basis 105° C

Plate XLIV

LOTUS CORNICULATUS

Root Development at 91 Days from Date of Seeding in

Chehalis Clay Loam



top

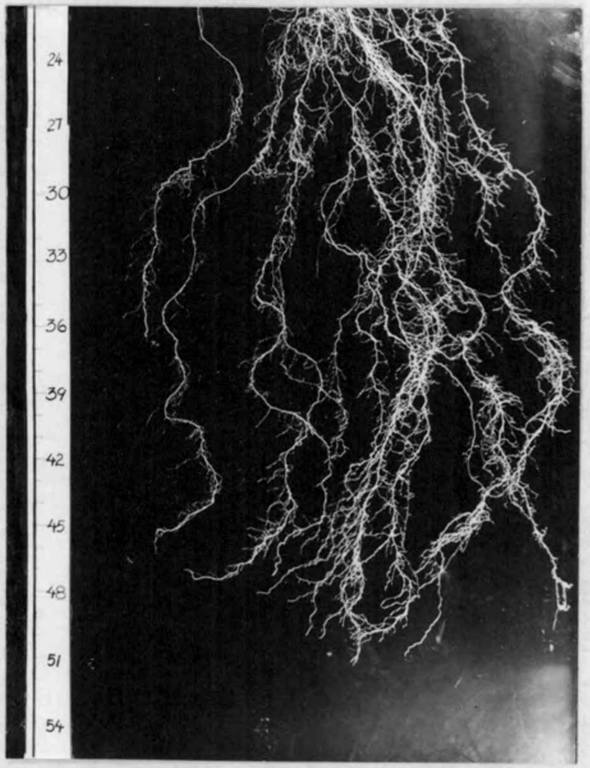


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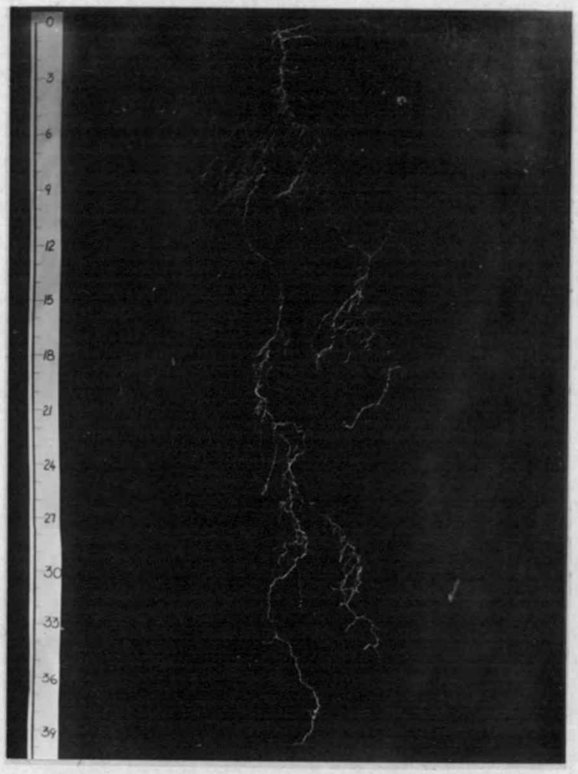
Plate XLV

LOTUS CORNICULATUS

Root Development at 129 Days from Time of Seeding in

Melbourne Clay



3. <u>White</u> <u>Sweetclover</u> (Melilotus alba)

Review of the data presented in Table XX and observations of Plates XLVI to XLIX shows that lateral growth, root penetration, and weights of roots and tops are all decidedly greater in the chehalis soil than in either the Willamette or Melbourne soil. The influence of soil structure and texture was very pronounced. Plants growing in Chehalis clay loam were coarser and more vigorous than plants in the other soil types, (Plates XLVI to XLIX). In plants growing in Willamette clay there appeared to be a profuse branching at a depth of 33 inches. The increase of branching may be due to the greater amount of available phosphorous which occurred in this zone, (Table XXIII).

The vigorous plant growth in Chehalis was due to an abundance of plant nutrients, excellent structure, and the deepness of this soil, (Table XXII).

Root development was limited to 36 inches in the Melbourne soil because of bed rock, which was encountered at that depth.

Sweetclover, at 166 days from date of seeding, reached a depth of 92 inches in Chehalis clay loam; the greatest depth reached by any crop during this study.

Table XX

Root and Top Development of Sweetclover Plants at Various Ages

Soil Type	Chehalis Clay Loam		Willamette Clay	Melbourne Clay
Month of Observation	Aug.	Sept.	September	September
Age (days from seeding)	98	166	133	145
Root penetration (inches)	78	92	63	36
*Weight of roots (grams)	10.52	14.9	1.09	.3
Depth at which majority of feeder roots are located (inches)	33-63	36-72	27-45	18-27
Diameter of root system (inches)	14	14	14	10
Length of top growth (inches)	28	36	13.5	8.5
Weight of top (grams)	11.25	17.1	1.52	.28

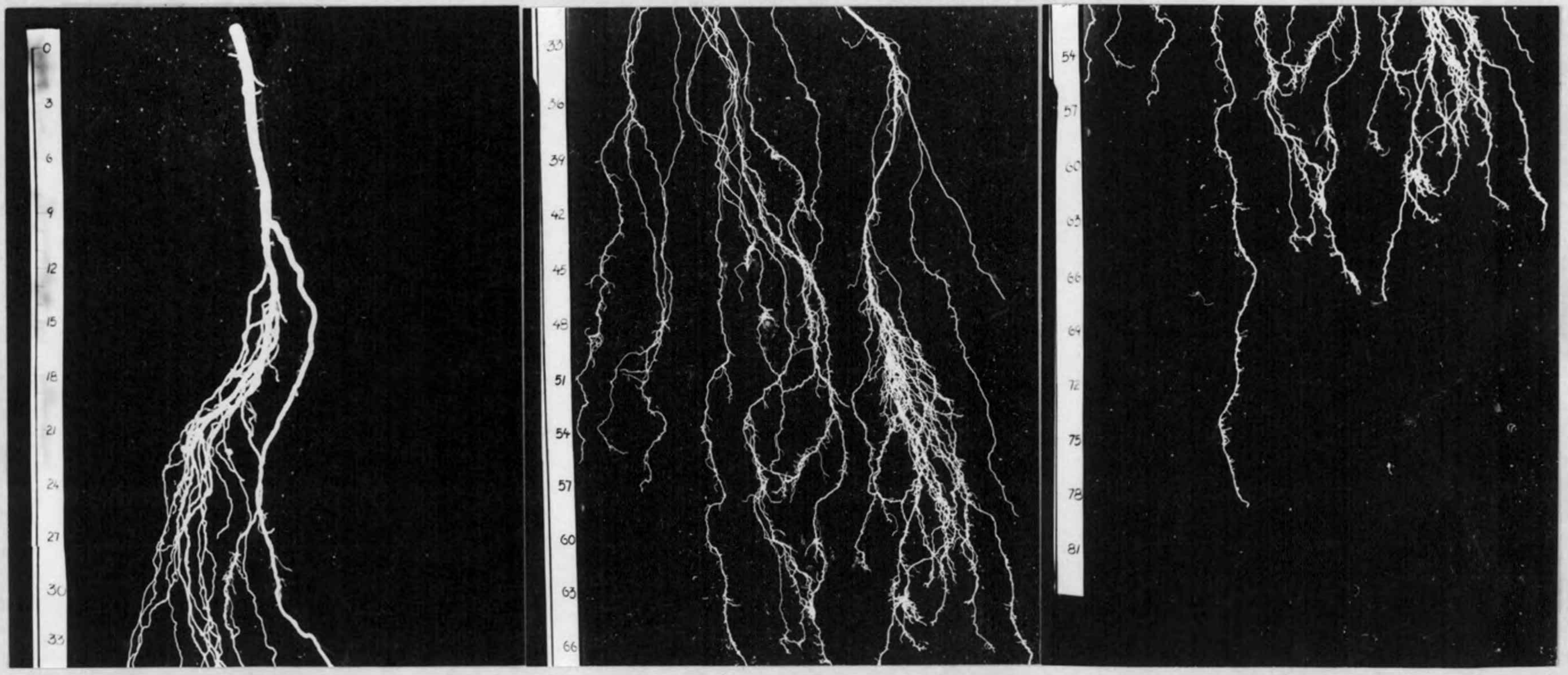
*Oven-dry basis, 105° C

Plate XLVI

WHITE SWEETCLOVER

Root Development at 98 Days from Time of Seeding in

Chehalis Clay Loam



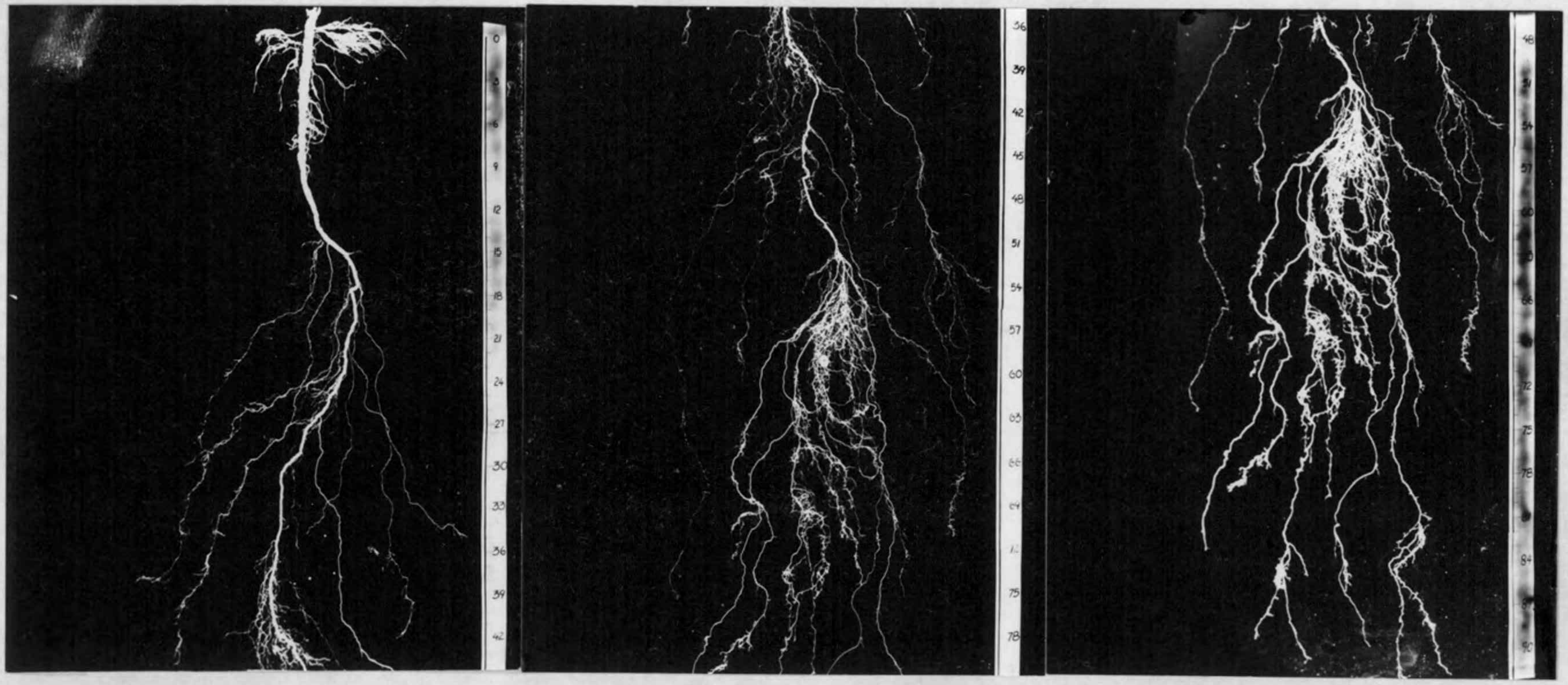
top center bottom

Plate XLVII

WHITE SWEETCLOVER

Root Development at 166 Days from Time of Seeding in

Chehalis Clay Loam



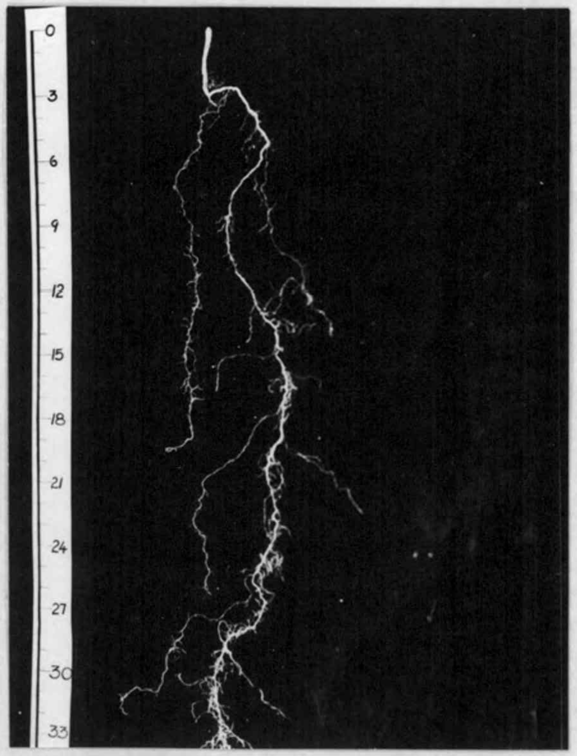
top center bottom

Plate XLVIII

WHITE SWEETCLOVER

Root Development at 133 Days from Time of Seeding in

Willamette Clay



top

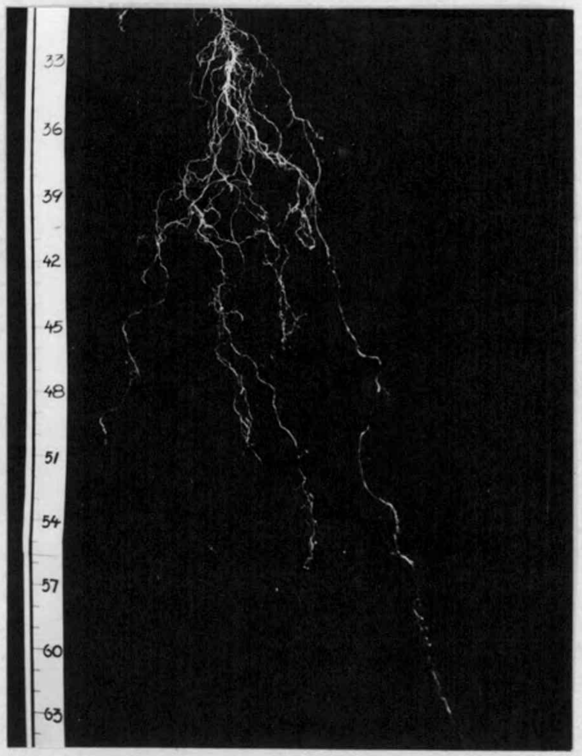


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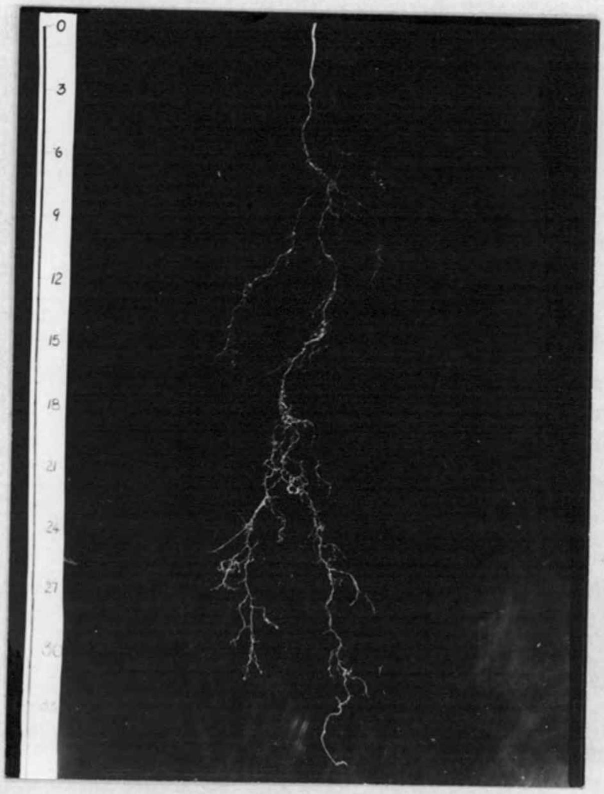
Plate XLIX

WHITE SWEETCLOVER

Root Development at 145 Days from Time of Seeding in

Melbourne Clay



4. Alfalfa (Medicago sativa)

Comparison of the observations made on alfalfa in the three soil types is presented for convenience in Table XXI and Plates L to LII. Depth of root penetration, weight of roots and tops indicate that those plants in Chehalis are superior in development to those plants growing in the other soil types.

That soil texture and structure has a decided influence on root development is shown by the above mentioned plates. Roots of plants grown in the Chehalis soil, which has an open porous structure, (Table XXII), are distinctly coarser and less branches than those roots occurring in the Willamette clay, which has a moderately compact structure as shown by Table XXIII.

Root growth was limited in the Melbourne soil because of out croppings of bed rock, and shortage of available nutrients and water supply, (Table XXIV).

Table XXI

Root and Top Development of Alfalfa
Plants at Various Ages

Soil Type	Chehalis Clay Loam		Willamette Clay		Melbourne Clay	
Month of observation	June	Aug.	July	Sept.	June	Sept.
Age (days from seeding)	46	104	59	118	47	115
Root penetration (inches)	22	66	35	63	21	29
*Weight of roots (grams)	.21	7.37	1.55	5.96	.06	.18
Depth at which majority of feeder roots are located (inches)	3-12	18-65	5-27	12-54	5-15	12-26
Diameter of root system (inches)	5	7	7	7	3	3
Length of top growth (inches)	9	24	11	16	3.5	6
Weight of top* (gram)	.37	5.84	1.57	4.14	.06	.19

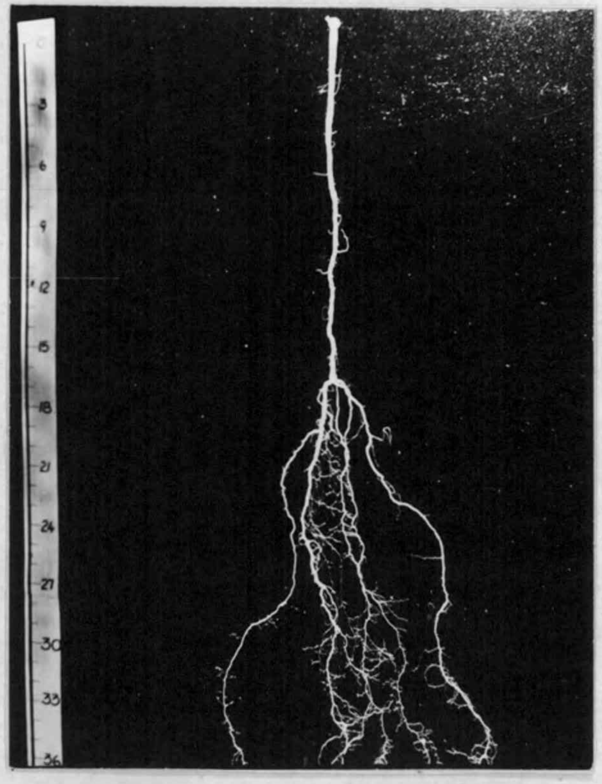
*Weights based on 105° C

Plate L

ALFALFA

Root Development at 104 Days from Date of Seeding in

Chehalis Clay Loam



top

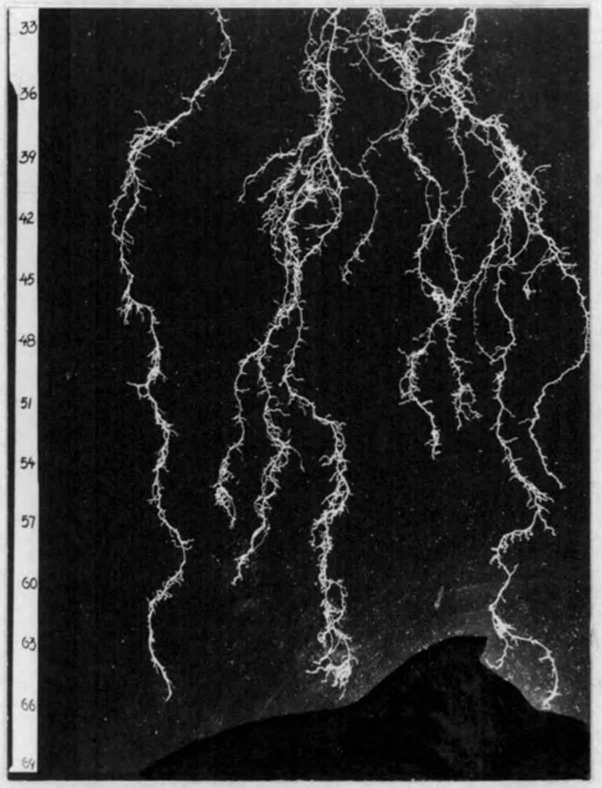


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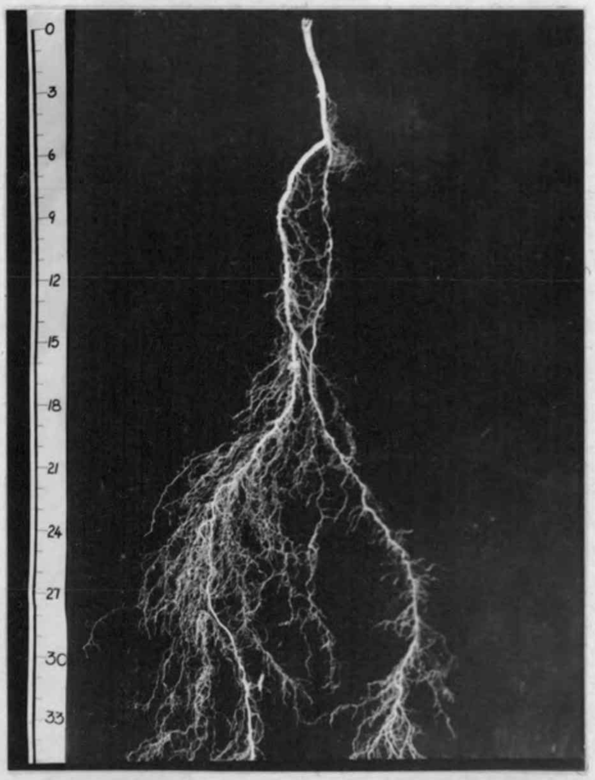
Plate LI

ALFALFA

Root Development at 118 Days from Date of Seeding in

Willamette Clay



top

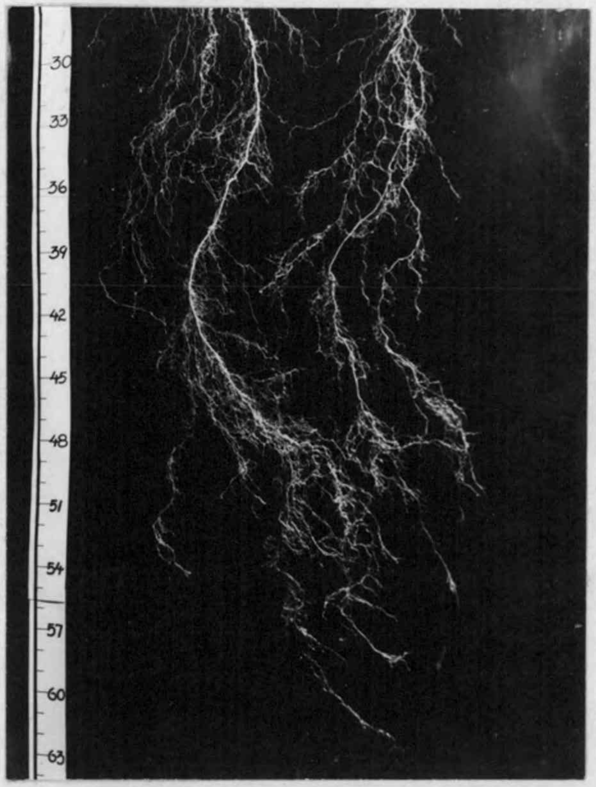


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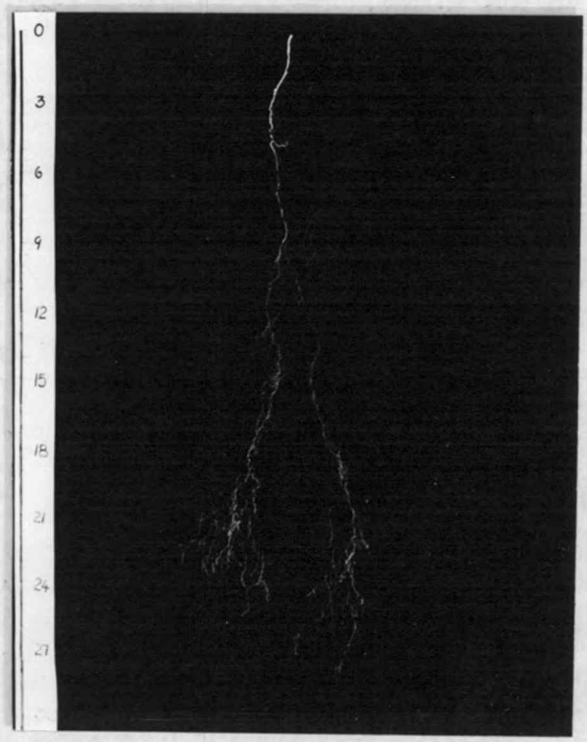
Plate LII

ALFALFA

Root Development at 115 Days from Time of Seeding in

Melbourne Clay



C. Physical and Chemical Properties of the Soils Used in Connection with This Study:

The soil types used in this study are: (1) Chehalis clay loam, (2) Willamette clay, and (3) Melbourne clay. Data obtained are given in the form of tables and general description.

Chehalis Clay Loam

1. General Description

The surface soil of Chehalis clay loam consists of rich-brown mellow clay loam. The soil grades downward into lighter colored, more compact yet freable clay loam that is continuous to a depth of 40 inches. Below this depth the soil is slightly darker consisting of clay loam extending to a depth of 7 feet or more without material change.

This soil occupies the second bottoms and has smooth or gently undulating surface. Except during periods of flooding, drainage is good. This is indicated by absence of mottling in the lower levels.

2. Structure

Structure is an important characteristic in the study of the soil profile.

The structure of this soil, as indicated by the porosity determinations (Table XXII) is excellent and fairly constant throughout the depth studied. The capillary openings, which furnish water storage capacity to a soil ranging from 35.6 to 43.5 per cent, shows definitely that this soil has considerable water retaining ability. With the large amount of non-capillary pores present, it is evident that the soil is well aerated throughout and has excellent drainage. The reduction of total and non-capillary pore space between 12 and 18 inches was due to a tillage pan developed in that zone.

Soils to be in optimum condition for plant growth should contain approximately 50 percent pore space. This 50 percent should be composed of about three-thirds capillary and one-third non-capillary openings. As shown in Table XXII, Chehalis clay loam closely approaches this ideal.

3. Texture

The mechanical analysis of this soil places this series in the clay loam class.

The figures given in Table XXII indicates considerable eluviation of the finer soil separates and that soil horizon development in taking place. Per cent of colloids is approximately twice as great from 36 to 66 inches deep as it is in the surface 18 inches of soil. They clay has also begun a migration from the surface layers to a deeper position. Still further evidence of this movement is given by the location of the sand. The surface 18 inches contains three times as much coarse material as the zone of 36 to 66 inches, (Table XXII).

4. Available Nutrients

The chemical analysis, Table XXII, shows clearly that this soil is very fertile. The depth at which nitrates were found is outstanding. This not only indicates that nitrates are available at great depths but this condition applies to other plant nutrients as well. The zone available for root development in this soil is large. Evidence of this is given in Table XXII.

Willamette Clay

1. General Description

The surface soil of Willamette clay consists principally of an 8 to 10 inch layer of rich-brown clay and contains sufficient silt, sand, and organic matter to make it loose and friable. This rests upon a brown and yellow mottled compact clay which grades downward into a light brown and yellow mottled subsoil. It has a gently sloping to slightly undulating surface. The top soil is well

Table XXII

Physical and Chemical Properties of Chehalis Clay Loam

Depth	Pore Space			Mechanical Analysis				Chemical Analysis			
	Total	Capillary	Non-Capillary	Sand	Silt	Clay	Colloids	pH	* O.M.	** NO_3	# P
inches	%	%	%	%	%	%	%		%	p.p.m.	p.p.m.
0-6	52.1	35.6	16.5	46.0	31.0	23.0	17.5	6.4	2.6	41	230
6-12	51.7	36.1	15.6	48.0	28.0	23.0	17.5				
12-18	50.2	39.0	11.2	46.0	30.3	23.7	17.5	6.4	2.3	24	241
18-24	53.2	48.2	15.0	40.0	30.0	30.0	23.7				
24-30	52.8	38.4	14.4	30.5	34.3	35.2	25.2	6.4	2.4	25	400
30-36	57.7	40.4	17.3	20.2	39.3	40.5	29.7				
36-42	59.2	34.7	21.5	15.8	44.2	39.4	30.8	6.4	2.3	20	380
42-48	58.9	38.1	20.8	15.8	44.6	39.6	32.8				
48-54	62.3	39.3	23.0	14.6	44.6	40.8	33.2	6.4	1.8	32	380
54-60	61.5	40.0	21.5	15.8	43.4	40.8	33.2				
60-66	56.6	36.5	21.0	14.2	42.8	43.0	33.2	6.4	0.6	7	380
66-72	57.0	43.3	13.7	14.2	48.8	37.0	29.4				
72-78	57.0	43.5	13.5	16.2	46.6	37.2	29.6	6.6	0.6	7	375

* Organic Matter
** Nitrate Nitrogen
\# Available Phosphorus

drained but water movement through the lower compat soil is restricted.

2. Soil Horizons

This soil is mature and has a well developed profile. The A horizon extends from 0-26 inches, is rich-brown in color and friable to a depth of 8 inches. At this depth a tillage pan has developed which is vary compact. The B_1 horizon is brown, moderately compact, and extends 26 to 33 inches in depth. The B_2 horizon or illuvial zone extends from 34 to 74 inches and is brown and yellow mottled, hard and compact, and contains numerous concretions. The greater portion of the non-capillary openings have been filled up with the eluviation of the finer separates. The C horizon is light-brown and yellow mottled and extends beyond 74 inches.

3. Structure

Except for a tillage pan, Willamette clay has excellent structure in the top 24 inches, but the lower horizons are only fair, (Table XXIII). The lack of non-capillary pores below 24 inches shows lack of aeration and drainage. This soil has a large water storage capacity as shown by the high percentage of capillary openings.

The decrease of non-capillary openings in the lower horizons is due to the clogging with fine colloidal material carried from the surface soil. Colloids as shown in the table are approximately 5 to 10 per cent higher in the B horizon than in the surface soil.

4. Texture

The per cent of sand, silt, and clay determined in the mechanical analysis of this soil, classified it as a clay.

Eluviation has been active in this soil for some time. Evidence of this is easily seen by the mechanical analysis, (Table XXIII). The sand gradually decreases in percentage to a depth of 36 inches and then increases. Per cent clay and colloids increase slightly to a depth of 36 inches and then decrease. The cause of such a phenomenon is due to the migration of clay and colloids downward with their deposition at approximately 36 inches.

5. Available Nutrients

The chemical analysis (Table XXIII) shows Willamette clay to be quite fertile. The presence of nitrates in the lower horizons gives evidence that this soil has an extensive area of available nutrients. Some of this nitrate in the lower horizons may be accounted for by leaching because growth of the crops at this time was not sufficient to utilize it.

The pH of this soil gives evidence that the podzolization process has become active.

Lack of utilization of the subsoil in indicated by the low percentage of organic matter found there.

This soil has an abundant supply of available phosphorous at all levels except the third foot. This low amount of available phosphorous in this zone may be due to phosphorous removal influenced by moisture relationships which confined the feeding roots during the summer months to this level of soil.

Willamette clay is easily cultivated and responds well to good management.

Melbourne Clay

1. General description

The surface soil of the Melbourne clay consists of 6 to 8 inches of reddish-brown clay containing sufficient sand and silt to give it a comparatively friable structure. The subsoil has two sections, and upper layer consisting of a brown to a reddish-brown friable heavy clay, and a lower layer of brown and yellow mottled moderately compact clay. The sandstone from which this soil is derived was encountered at an average depth of 36 inches. Small fragments of the bed rock were intermixed with the subsoil.

Table XXIII

Physical and Chemical Properties of Willamette Clay

Depth	Pore Space			Mechanical Analysis				Chemical Analysis			
	Total	Capillary	Non-Capillary	Sand	Silt	Clay	Colloids	pH	O.M.*	NO_3**	P#
inches	%	%	%	%	%	%	%		%	p.p.m.	p.p.m.
0-6	54.6	37.1	17.5	24.4	44.8	30.8	25.8	6.0	2.65	28	204
6-12	54.3	40.0	14.3	18.8	48.4	32.8	26.4				
12-18	63.6	36.8	26.8	17.4	48.2	34.4	30.8	6.0	1.70	22	176
18-24	51.7	38.3	13.4	18.8	43.8	37.4	31.2				
24-30	52.8	43.0	9.8	18.6	43.4	38.0	35.4	6.2	0.33	34	92
30-36	52.5	45.7	6.8	16.6	44.4	39.0	36.8				
36-42	52.5	43.7	8.8	15.4	43.6	41.0	33.2	6.4	0.13	12	120
42-48	51.3	42.9	8.4	17.6	45.7	37.2	28.2				
48-54	52.4	44.4	8.0	18.6	42.6	34.2	27.2	6.6	0.13	7	182
54-60	53.2	44.8	9.2	19.4	51.4	29.2	23.4				
60-66	52.1	46.0	6.1	20.6	49.8	29.6	22.8	6.6	0.02	7	232
66-72	52.1	46.6	5.5	20.2	52.0	27.8	22.4				
72-78	52.5	45.4	8.2	20.6	51.8	27.6	21.2	6.6	0.02	7	306

* Organic Matter
** Nitrate Nitrogen
\# Available Phosphorus

The topograhy is rolling, and this soil has very good drainage. A tillage pan, 6 to 10 inches in depth, has developed in this soil.

2. Soil Horizons

Much of the A horizon in this soil has been lost by erosion. It is 0 to 6 inches in depth, has fair structure and is reddish-brown in color. The B_1 horizon extends from 6 to 15 inches in depth, is moderately compact and has a reddish-brown color. The B_2 horizon extends from 15 to 28 inches in depth. It is moderately compact and ha a light-brownish to yellow mottled color. The C horizon extends from 28 to 36 inches, and is brown and yellow mottled in color. Below this depth bed rock is encountered.

3. Structure

The porosity of Melbourne clay, (Table XXIV), shows this soil to be only fair in structure. Capillary pore space is high and indicates a moderately compact soil with considerable water holding capacity. However, crops grown on it usually suffer because of lack of moisture resulting from its shallowness. The non-capillary openings although not excessive insure fairly good aeration and drainage.

4. Texture

This Melbourne soil is a clay, (Table XXIV). The percentage of sand is least at a depth of 18 to 24 inches; whereas, the clay and colloidal fractions are greatest in these depths. The finer separates in this soil, as in the Willamette clay, have undergone eluviation.

5. Available Nutrients

The nutrients present in this soil type are decidedly less than in either the Chehalis clay loam or Willamette clay soils.

The pH of this soil is lower than in either Chehalis or Willamette. That the podozolization process has been active is evident by the leaching of the bases from the surface soil.

Table XXIV

Physical and Chemical Properties of Melbourne Clay

Depth	Pore Space			Mechanical Analysis				Chemical Analysis			
	Total	Capillary	Non-Capillary	Sand	Silt	Clay	Colloids	pH	O.M.*	NO_3**	P#
inches	%	%	%	%	%	%	%		%	p.p.m.	p.p.m.
0-6	50.2	38.6	11.6	25.8	31.5	42.7	36.7	5.4	2.06	20	19
6-12	46.3	36.2	10.1	26.3	28.2	45.5	40.7				
12-18	49.1	34.7	14.4	25.0	29.5	45.5	41.7	5.4	1.38	21	12
18-24	48.7	32.1	16.5	23.8	30.2	46.0	42.2				
24-30	59.2	41.7	17.4	30.0	27.8	42.2	38.0	5.6	0.77	6	13

* Organic Matter
** Nitrate Nitrogen
\# Available Phosphorus

DISCUSSION

From a review of the tables and plates previously presented the perannial legumes studied can be cassified into two general groups: (1) Those which are deep feeders, namely, alfalfa, sweetclover, lotus, and red clover; and (2) Those which are comparatively shallow feeders, namely, alsike, white Ladino, and strawberry clover.

Of those crops observed during the winter months, Ladino clover produced the largest and most extensive rooting system and strawberry clover the least. However, white clover and strawberry clover produced the most extensive lateral root development of any of the clover studied.

Observations made on the above crops in the summer showed that root development at this time was much faster than during the winter months. As shown in Plates XIII, XXIII, XXXIII, and XL1, white clover had the most extensive root system of any clover, and strawberry clover the least. All root systems were profusely branched and were most active in the lower portion of the root system.

Alfalfa, sweetclover, and lotus all produced a root system of similar pattern. They were comparatively simple, consisting principally of a strong taproot with numerous laterals. The root system of sweetclover penetrated to a greater depth than either alfalfa or lotus, whereas, lotus produced the most profusely branched root system.

Red clover's root system was similar to the other _Trifoliums_ studied except that it penetrated deeper and was more extensive.

All crops studied grew vigorously in the Chehalis soil and the greater portion of them grew fairly well in the Willamette soil, but none of the crops appeared to be adapted to the Melbourne soil. However, of the crops observed, sweetclover grew the best in this latter soil.

A. Soil Moisture

Weaver and his co-workers (70, 71, 72, 74) are of the opinion that changes in lateral spread of roots, depth of root penetration, or output of branches are correlated in nearly every instance with changes in water content. Similar conclusions were reached by the writer in this study.

In observations made during the winter months, when moisture was not a limiting factor in root development, the lateral roots were concentrated in the surface few inches of soil and extended directly outward. As the winter rains ceased and the top soil became dryer, lateral extension stopped and growth downward took place. It is believed by some investigators that competition between neighboring plants caused lateral growth to turn downward. This is undoubtedly true but the author is of the opinion that this competition causes a drying of the soil which forces the laterals to change their direction. It is a common knowledge that roots respond to changes of moisture in the soil, and that they are positive in their reaction, turning from a lower to a higher water content providing sufficient aeration is present, Miller (40).

Observations during the dry summer months, when moisture was a limiting factor, showed that in all soils the zone of greatest root activity was in the lower portion of the rooting systems. The surface 15 inches of soil was almost completely lacking in lateral roots. This condition can be explained only by moisture relations to root growth. During the summer months the upper soil had become so depleted of moisture that root growth was stopped and much of that present was disintegated. The complete reversal of the feeding zone of red clover due to moisture received in the fall further proves the reasoning that moisture is directly correlated to the feeding zones of roots. The reversal of feeding roots as indicated by this crop is of outstanding importance. In its life time such a plant would return and distribute great quantities of organic matter throughout the soil.

In the application of commercial fertilizers this information on the distribution of feeding roots is very valuable if the highest possible returns are to be realized

As a general rule fertilizers are applied on the surface of the ground. If such applications are made late in the spring or summer when there is not sufficient rain to carry the plant nutrients down to the summer feeding zones, it is unlikely that any beneficial results will be obtained from such applications. However, if applications are made in the fall or very early spring the summer feeding roots can more fully utilize them.

B. Soil Structure and Texture

The influence of soil structure is reflected mostly in lateral growth, degree of fineness of the roots and taproot penetration.

In nearly all cases roots growing in the Chehalis clay loam, which is very open and porous (Table XXII) were larger and of a coarser texture. This coarseness became more pronounced as the crops matured.

The effect of the tillage pans in the Willamette and Melbourne soils was very pronounced. Observations made in the winter on alsike, white, Ladino, and strawberry clover showed definitely that as the roots entered these tillage pans they were reduced in size and the number and spread of laterals decreased. When through the hard pan the size of the taproot and the number and spread of laterals increased. That a hard and compact soil limits the extent of root systems, has been noted by Weaver (68). He found that in compact soils the roots are more or less contorted and kinked. The writer in his observations found this to be true when the percentage of moisture was low in these compact zones. However, when moisture was not a limiting factor, the effects of this compact soil resulted in a reduction of root size and a decrease in number and spread of laterals. The tillage pan present in the Chehalis soil had little effect on the root systems. This was probably because of the high percentage of sand present in this soil, (Table XXII).

Root penetration was greatest in the Chehalis clay loam. This indicates that plants growing in a soil with less mechanical resistance tends to grow to a greater depth than plants in a finer textured and more compact soil.

The depth obtained by alfalfa and sweetclover in the Willamette clay is of outstanding importance. Roots penetrating this compacted, somewhat impervious subsoil would do much to improve the structure, and by doing so increase the aeration, drainage, and feeding zone.

C. Plant Nutrients

Plant nutrients also have a direct relationship to the development of the root systems of crops. The writer believes that the earliest evidence of the influence of soil types is due largely to the available nutrients as shown by the difference in growth on the three soil types, (Table XXII, XXIII, and XXIV).

Numerous experiments in water culture have been carried on to determine the influence of different concentrations of plant nutrients on the extent of root development. Results from these experiments have shown that in comparison to the amount of top growth produced the root systems are more extensive in the cultures of low concentrations. This suggests that the deeper root penetration in the Melbourne soil of alsike, white, and Ladino clover during the winter when an abundance of moisture was present, may have been due to the small amount of available nutrients.

D. Factors Limiting Root Penetration

That soil obstructions tend to limit root development is an accepted fact. Weaver and Crist (70) working in the great plains found that root growth was limited by a calcareous hard pan.

Headden (27) found alfalfa roots ceased to descend upon encountering the water table. This is to be expected because under such conditions it would be impossible since aeration would be lacking below this level.

Plants grown in the Melbourne plots were limited in their penetration by an impervious layer of bed rock which occurred approximately 36 inches from the soil surface.

E. Reaction of Roots to Non-capillary Pore Spaces

It was of considerable interest to the writer to note the reaction of roots to the non-capillary openings of the soil. Roots upon encountering pores just large enough to accommodate them, and going somewhat in the same direction, tended to follow them for a great distance as though trapped. However, if the openings were three-eighths inch or larger in diameter, the roots twisted about and often folded back upon themselves several times until conditions developed enabling them to re-enter the soil.

SUMMARY

Observations were made on the root systems of eight of the more important perennial legumes from the standpoints of crop rotations, soil conservation, and forage and seed production in the western Oregon. These plants were seeded in Chehalis clay loam, Willamette clay, and Melbourne clay, three representative soil types of the Willamette Valley soils.

The objectives of the study were to determine the influence of soil types on root development; to ascertain a more complete knowledge of the activities of the rooting systems of legumes; and to determine which soils were most suited to perennial legume root growth.

The results show that:

1. Perennial legumes studied can be classified into two general groups; (a) Deep feeders, namely, alfalfa, sweet-clover, lotus, and red clover, and (b) Shallow feeders, namely, alsike, white, Ladino, and strawberry clover.

2. Little difference was shown on the early root growth of the legumes on the different soils.

3. The influence of soil types on the root system is cumulative with age.

4. The feeding zone of roots are controlled principally by moisture relationships. Such factors as available nutrients structive and organic matter appeared to be secondary

importance in this experiment.

5. Moderately compact soils tend to produce finer textured root systems than more open porous soils.

6. Tightly compacted zones (tillage pans) appeared to cause a reduction in the number and spread of laterals; and the taproot is penetrating it was reduced in size, flattened, and at times contorted.

7. Root penetration was greater in open textured soil at maturity than in moderately compact soils.

8. Availability of plant nutrients appeared to show some influence on root development earlier than did the physical factors of the soil.

9. Bed-rock prevented root penetration in the Melbourne soil.

10. Roots tended to follow small non-capillary pore spaces in their downward passage but avoided the larger non-capillary openings.

11. Chehalis clay loam is the best soil type for all perennial legumes studied. However, alfalfa and sweetclover grown fairly well on the Willamette clay soil type.

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