ROOT DEVELOPMENT OF COTTON, PEANUTS AND TOBACCO IN CENTRAL OKLAHOMA

W. E. Bruner

Plants cannot be so intelligently handled and their responses can not be so correctly interpreted when one's knowledge is confined to the above-ground parts as when the roots are also taken into consideration. The part of the plant which is below the surface of the ground is usually equal to and often more extensive than the portion above the surface of the soil. Roots are always more intricately branched than the shoot, and their development and activities are closely related to the activities of the shoot.

A knowledge of the manner of branching, the depth of penetration and the lateral spread of the root systems, and of the working or absorbing areas of the different seasons, makes possible a more intelligent interpretation of the responses of the plant to the various factors of its environment. Recently much interest has been shown in descriptive and experimental studies of root behavior under field conditions. Little work has been done, however, on the roots of plants included in this paper and there is no record of any done in this vicinity. Accordingly descriptions of the root development and illustrations of the root systems of cotton, peanuts, and tobacco, taken at various stages in their development, should be a useful addition to our knowledge concerning these plants, particularly when the record is made under known environmental conditions. An intensive study of these plants was carried out in Oklahoma during the growing seasons of 1925 and 1926.

SOIL

The plat on which the studies were made was a level area in which there were no abrupt changes in soil conditions The soil was a fine, sandy loam, reddish-brown in color which, at the surface, contained enough clay to cause it to become compacted and bake if cultivated while too wet.

It contained no gravel and only at a depth of four to six feet did as much as one per cent of coarse sand occur. About 2 per cent of medium sand was found in the first three feet. This increased to nearly 4 per cent at a depth of six feet. The soil at all levels contained more than 50 per cent fine and very fine sand. The average per cent silt to a depth of six feet was 22, the variation being 13 to 28 per cent for the six one-foot layers examined. Clay varied from 18 to 27 per cent and averaged 26.6 per cent. The layers in which clay was more abundant contained less silt. This open sandy-loam soil was easily penetrated by the roots and excavation was accomplished more easily than in heavier types of soil.

TILLAGE

The seed bed was prepared early in March. Debris, which would interfere with root studies, was removd. The plat was plowed six inches deep and harrowed. The soil was in good tilth and in excellent condition to receive the seed or plants at the proper time. The experimental plats were six rows wide and the rows were three and one-half feet apart. The plants were suitably spaced in the rows.

Cultivation was accomplished by use of a horse-drawn harrow of suitable width which formed a shallow surface mulch without disturbing the roots. A mulching fork and hoe were used in addition to keep the soil perfectly mulched and free from weeds and grass. The roots of grass and weeds would interfere, not only with the excavation and investigation, but also with the development of the roots of the crop plants. The depth of the cultivation hardly ever exceeded one inch.

METHOD OF MAKING ROOT EXCAVATIONS

A deep trench wide enough to permit one to work with ease was dug at one side of the plants to be examined. The soil was then carefully picked away from below with an ice-pick until the extremities of the roots were discovered. The roots were then followed from the tips toward the base of the plant. They were carefully described as the excavation proceeded and drawn in pencil in the field. Numerous portions of the roots were preserved for reference until the drawings were traced in ink and the written descriptions were in their final form.

Washing roots from the soil for the purpose of making photographs was tried repeatedly. It was not found to be successful because a current of water strong enough to carry away the soil broke many of the roots and pulled the others from their natural position. Under these conditions, photographs did not show the proper relationship of the roots. Carefully executed drawings were found to portray the root systems more faithfully than any other method of illustrating them.

ENVIRONMENTAL CONDITIONS

Records of the precipitation, available moisture in the soil, the evaporating power of the air, and average day and night temperatures were kept during the growing season while the root studies were in progress.

PRECIPITATION

Precipitation during April and May, 1925, was 5.9 and 8.7 inches respectively. This was sufficient thoroughly to moisten the open surface soil of the experimental plats and to increase the reserve in the subsoil. Little rain fell in June but 3.7 inches which fell during July moistened the upper layers of soil. August was dry and the supply of available moisture in the soil was almost exhausted.

Precipitation from April to July inclusive was 11.5 inches in 1926. Although this was 3.6 inches below normal, heavy fall rains and winter moisture had thoroughly dampened the soil and subsoil. As a result, a supply of moisture, sufficient for good growth, was present throughout the summer.

SOIL MOISTURE

Weekly determinations of soil moisture were made throughout the period of plant growth. Samples of about 100 grams of soil were secured by means of a soil tube each week. They were secured at depths of 0 to 6 inches, 6 to 12 inches, 18 to 24 inches, 24 to 36 inches and 36 to 48 inches. The samples were oven-dried and a record kept of the water content of the soil in excess of the Hygroscopic Coefficient. This is approximately the amount available for plant use. Thus, a careful check on the water-content of the soil was made during the two growing seasons.

The soil was moderately dry on April 8, 1925, but the water content increased rapidly as a result of spring rains. Early in June it began to decrease and this continued until the last of July when a rain wet the surface 12 to 15 inches. Thus the early part of the growing season was characterized by a relatively large amount of available soil moisture. There was an abundance of moisture present in the soil when the plants began their growth in 1926. Moisture was abundant throughout the season but decreased considerably late in July.

EVAPORATION

Relative humidity and its influence on transpiration have an important bearing on root growth. The moisture in the air is often a controlling factor in the development of the plant. In Oklahoma plants not infrequently wilt early in the day owing to excessive water loss by the leaves.

Wilting has been shown to stop or seriously retard food manufacture and growth during the period when the cells are not turgid. This modifies the development of the roots. Water loss from the plant and evaporation from the soil correlate closely with evaporation from Livingston's porous cup atmometers which are recognized as standard instruments for measuring evaporation.

Accordingly cylindrical cups, provided with mercury traps to prevent absorption, were used to secure the average daily evaporation for each week. There was a gradual increase in water loss as the season became warmer although several days of excessively high or unusually low evaporation resulted from rain or dry, windy weather on different occasions. The minimum evaporation for any week was 6.1 cubic centimeters for the week ending May 13, 1925. The maximum, 69.8 cubic centimeters was the average daily evaporation for the week ending July 22, 1925. Evaporation was not excessive at any time during 1926. This correlates with the moderate temperatures of the season.

AIR TEMPERATURE

A Friez Thermograph was placed in the field for the purpose of securing temperature records. The average day temperature for the week was secured by averaging all of the temperature readings taken, at two hour intervals, from 8 a. m. to 6 p. m. Night temperatures were secured in a simillar manner from readings taken from 8 p. m. to 6 a. m. The extreme range through which the temperature fluctuated is shown by the maximum and minimum temperatures. Temperatures became favorable for good plant growth in April and increased during the growing season. A comparison of the temperature data for the two seasons shows that during 1925 the fluctuations were greater and extremes were much more severe than in 1926.

OBSERVATIONS ON ROOT DEVELOPMENT

A point, which it seems scarcely necessary to emphasize, but which may easily be lost sight of, is that roots grow as long as the plant is alive. This is necessary, for the plant must have a continuous supply of new absorbing rootlets and root hairs since these structures are ordinarily rather short lived.

Roots, for convenience, have been classified as permanent and temporary. The permanent roots consist of the taproot and its laterals or branches. Where the laterals branch and rebranch they have been designated as branches of the second and third order. All of these make up the permanent root system of the plant. Occurring on all of these roots of the permanent system were numerous temporary or diciduous roots which have been designated as absorbing rootlets. All root branches were absorbing rootlets for a week or so while they were tender, succulent and covered with root hairs. In fact, it was impossible to tell which were of a temporary nature and which were persistent until a greater length or diameter was attained by a small per cent of the branches. All of the rootlets which did not continue to grow in length and usually in diameter as well soon became functionless, shriveled and eventually disappeared. This took place as soon as the soil was dried out in the immediate vicinity of the rootlet. In case of an abundance of moisture as a result of frequent precipitation, it was observed that the diciduous roots were not shed for a somewhat longer period. Likewise a decrease in moisture caused the absorbing rootlets to disappear more rapidly. Thus, the actively absorbing portion of the root system varied in extensiveness with the soil moisture condition.

The functional period of the absorbing rootlets was of relatively short duration. Just which of the numerous rootlets were to persist and become

a part of the permanent root system seemed to be the result of their immediate environment. During a period of drouth all but a relatively small portion of the absorbing rootlets died. When the drouth was broken by an abundance of moisture there was a very rapid increase in the number and length of absorbing rootlets followed by a renewal of vigorous growth in the shoot.

In the case of cotton and peanuts this growth was almost wholly confined to the extremities of the roots. Only the younger portion being able to develop branches. Tobacco on the other hand, showed much more ability to produce absorbing rootlets on the older portion of the root. Hence a portion of the older roots which had lost their absorbing power might become reinvested with the capacity for absorption. This was accomplished by the development of a new supply of absorbing roots from meristimatic regions which persisted in the old root. Cotton and peanuts had this capacity only in a very limited degree.

COTTON

Mebane cotton was planted on May 10, 1925. The soil was in good tilth and warm enough to cause the seed to germinate at once. The plants came up quickly and developed quite rapidly. The rows were 3.5 feet apart and the hills were spaced about one foot apart in the row. According to the common practice several seed were planted in each hill to enable the young plants to break through the soil and to insure a good stand. They were thinned to one plant per hill when they were six inches high.

Root development was followed throughout the season. Root development in 1925 is summarized in the following paragraph. The detailed description is found in the 1926 descriptions. The plants were 8 inches tall by June 20 and the roots had penetrated to an average depth of 20 inches, the longest lateral roots spread, on the average, 15 inches to either side of the plant. Each root system occupied a cone-shaped area of soil which was being quite thoroughly dried-out by the root system as it developed. Soil samples taken on three successive occasions showed, particularly a little later in the season, that the network of the roots lowered the soil moisture nearly to the Hygroscopic Coefficient. The root systems were strikingly symmetrical and regularly branched. The younger roots were characterized by rather sharp, regular undulations as they proceeded through the soil. Root hairs were present and seemed to be functioning on all parts of the root system in very young plants. This condition existed for several days as was indicated by examination made during the early seedling stages. Root hairs appeared to be functional on only 3 to 6 inches of the extremities of the main roots of older plants. The absorbing rootlets which did not exceed this length were covered with actively absorbing root hairs except for about .5 inch at the very tip. The second excavations, on July 22, were made when the plants were 14 inches tall and beginning to branch. The total depth of penetration of the root was 30 inches and the average maximum spread in the various plants examined was 20 inches. Numerous large branches were developing from the taproot at a depth of 2.5 to 5 inches. All of the old roots had a characteristic yellow color and the absorbing rootlets had withered and disappeared. Only on the younger portion of the roots were the absorbing rootlets present. The older portions were also without root hairs and incapable of absorption. The final excavation was made on October 6. The plants were 3.5 to 4.5 feet high, and well branched and fruiting abundantly. The roots of the larger and more vigorous plants had penetrated to a depth of 5.5 feet. The presence of numerous root branches showed that much absorption was taking place at depths below 40 inches

where the subsoil was moist and capable of supplying water adequate for the needs of the plant.

ROOT DEVELOPMENT IN 1926

Cotton of the same variety was planted on April 15, 1926, about a month earlier than the average date for planting cotton in this vicinity. The soil was warm and moderately moist and the weather which followed was favorable to the development of cotton.

The cotton seedlings had four or five well developed leaves 1.5 to 2 inches long by May 15. The stems were about 4 millimeters in diameter and 6 inches high. The plants were in good condition and growing at a moderate rate. The root systems were strong and well developed. They penetrated deeply and had a good lateral spread. The taproot gave rise to laterals regularly at the rate of sixteen branches per inch on the older portion. The laterals varied from .5 to 1 millimeter in diameter. Four large laterals per inch occurred on the 2 to 5 inch portion of the taproot. The total number of branches in the 2-5 inch layer ranged from 25 to 38. Figure 1 shows a root system excavated at this time.

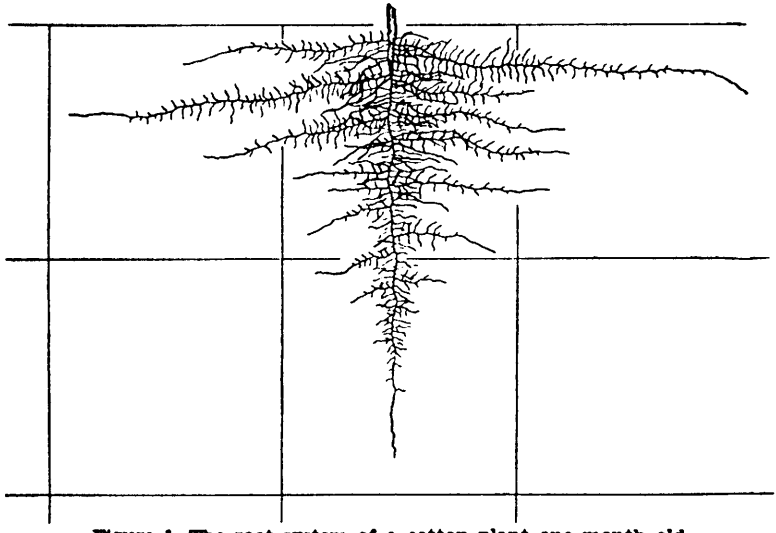

Figure 1. The root system of a cotton plant one month old.

The oldest and longest root branches had maximum lateral spread of 14 inches, while the taproot penetrated to a depth of 22 inches. Laterals were starting on branches and some had reached a length of 2 inches or more. They increased in length from a point, about 2 inches back from the tip, where they began, to the main taproot where they were 1 to 2 inches long. All of the roots were white and succulent at this time except the taproot, which was becoming slightly yellowish.

The second excavation was made about June 12. The plants were a foot high and growing rapidly. Short branches had formed in the axis of most of the leaves and flower buds were present on many of the stronger plants. On account of being planted early the plants were fully a month ahead of most of the cotton in the fields of the vicinity.

The upper portion of the taproot was found to have approximately

the same number of laterals, at this time as when the first excavation was made. In the root selected for use as an illustration eight of the main branches had increased in diameter to 1.5 millimeters and were pursuing a horizontal course in the soil. They started in the 3 to 5 inch level and ended in the 4 to 10 inch level. The branches were not as well supplied with laterals as most of the crop plants.

Ordinarily four to eight laterals, 2 to 3 inches long and .5 millimeter in diameter, occurred on each inch of the older portions of the root. The main taproot and the strong branches were tough and yellow to a depth of 12 inches, and to a distance of 14 inches on each side of the plant. The laterals were white and succulent. The roots penetrated to a depth of 31 inches and had a lateral spread of 23 inches. Laterals on the main branches were beginning to grow in length and in instances to increase in diameter. They, in turn, frequently bore absorbing rootlets at the rate of eight per inch. The general features of a sectional view is shown in Figure 2.

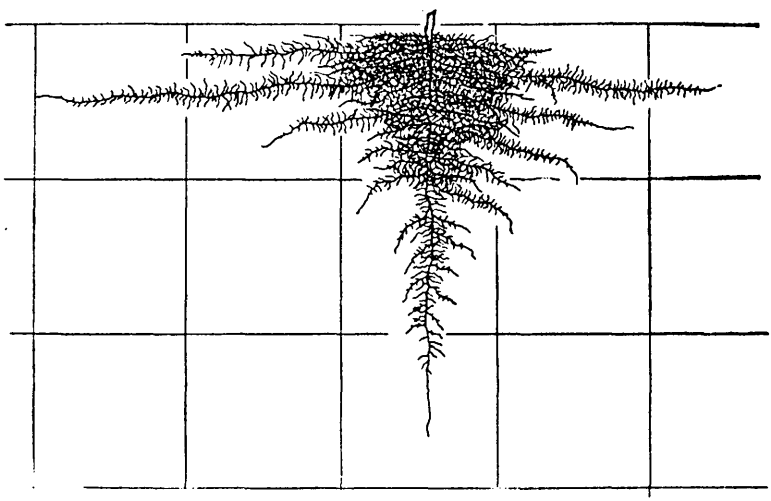

Figure 2. A cross-section of the root system of a cotton plant two months old, showing depth, lateral spread and manner of branching.

Cotton, which had grown at a normal rate in the warm, moderately dry soil of early spring, made a vigorous growth as a result of the warm June rains. An abundance of flowers and fruit developed about a month earlier than usual. This was possible only because of early planting and a favorable season. By July 23 the plants were 3 feet tall, stalky and well branched. Full grown bolls were present on the lower branches. The stems at the surface of the ground were .5 to 1 inch in diameter.

The examination of the root system revealed that the warm moist surface soil had stimulated vigorous root growth in the surface foot. The plants were large and vigorous, however, and numerous strong roots penetrated deeply into the moist subsoil.

Cotton has a relatively weak taproot below the first foot of soil. Many strong laterals were given off at a depth of 3 to 10 inches. Taproots, which were nearly 1 inch in diameter at a depth of 2 inches, tapered to a diameter of 3 millimeters at a depth of one foot, as a result of extensive branch-

ing. The largest of the branches occurred in the 3 to 6 inch layer of soil, only small branches being present in the 6 to 12 inch layer. Branches from the taproots in the second foot of soil were only about .5 millimeter in diameter. These branches were well supplied with absorbing rootlets. The taproots were only 2 millimeters in diameter to a depth of 24 inches. They gave rise to numerous absorbing rootlets in the 24 to 36 inch layer of soil. These rootlets occurred at the rate of six per inch. At 36 inches they were only 1.5 millimeters in diameter. The taproot of the plant figured ended at a depth of 46 inches. This was about the average depth of root penetration. In Figure 3 one strong lateral is shown which penetrated to a depth of 57 inches. This lateral followed an old root cast for 19 inches from a depth of 32 to 51 inches. This is a condition of normal rather than abnormal occurrence. Most soils which are regularly cropped are filled with old root casts which are frequently followed for considerable distance by the roots of the succeeding crop.

The laterals which were the longest were those which developed first in the seedling stage. They occurred at a depth of 3 to 4 inches and spread 30 to 40 inches. Near the extremities of the roots they intermingled with the roots of the plant in the rows on either side. In the case of the plant figured. One strong branch 9 millimeters in diameter grew horizontally, starting at a depth of 3 inches. It extended 35 inches where it ended at a depth of 9 inches. It gave rise to several small laterals and at a distance of 8 inches from the plant, there was a branch 2 millimeters in diameter. The horizontal branch had tapered to 5 millimeters at this point. The branch penetrated to a depth of 30 inches. Another large branch 1.5 millimeters in diameter occurred 2 inches farther from the plant. It grew almost horizontally for 20 inches. The first 10 inches of the horizontal root gave rise to branches which were in turn supplied with absorbing rootlets. The remainder of the root bore only unbranched absorbing rootlets which became shorter toward the tip. Root branches characteristically taper in this manner. Another strong horizontal root grew from the taproot at such an angle as to pass between the plants in the opposite row. It grew nearly horizontally for 59 inches. For a distance of 30 inches from the plant, it was sparsely branched and gave rise to only five branches throughout this distance. It tapered from a diameter of 7 millimeters at the plant to 4 millimeters, 30 inches from the plant, while at 48 inches from the plant it had a diameter of 1 millimeter. Six strong branches occurred at 40 to 42 inches from the plant. They were 12 to 18 inches long and well supplied with laterals. Some grew horizontally while others penetrated downward. This particular root was considerably longer than the average. Horizontal branches do not usually pass through the dense network of roots formed by the plants in the adjacent rows. The fact that this one had done so accounts for its unusual length. It seemed evident that the branches did not intermingle more because the soil was soon thoroughly dried out by the roots as they occupied it. Absorbing laterals occurred at the rate of four to eight per inch throughout the absorbing portion of the root system. Large branches apparently developed from the absorbing rootlets in response to soil conditions, hence, occurred without regularity on the older portion of the roots.

SUMMARY OF ROOT DEVELOPMENT OF COTTON

Cotton has a symmetrical, regularly branched root system which becomes yellow as the roots mature. The roots, in loam soil, usually penetrate somewhat more deeply than the height of the plant. They also spread more widely than do the branches. The root system has many times the number of branches found on the shoot. Most of the larger root branches arise at a depth of 3 to 6 inches. In the field where the stand is good, the roots ordinarily spread laterally only about 3 feet.

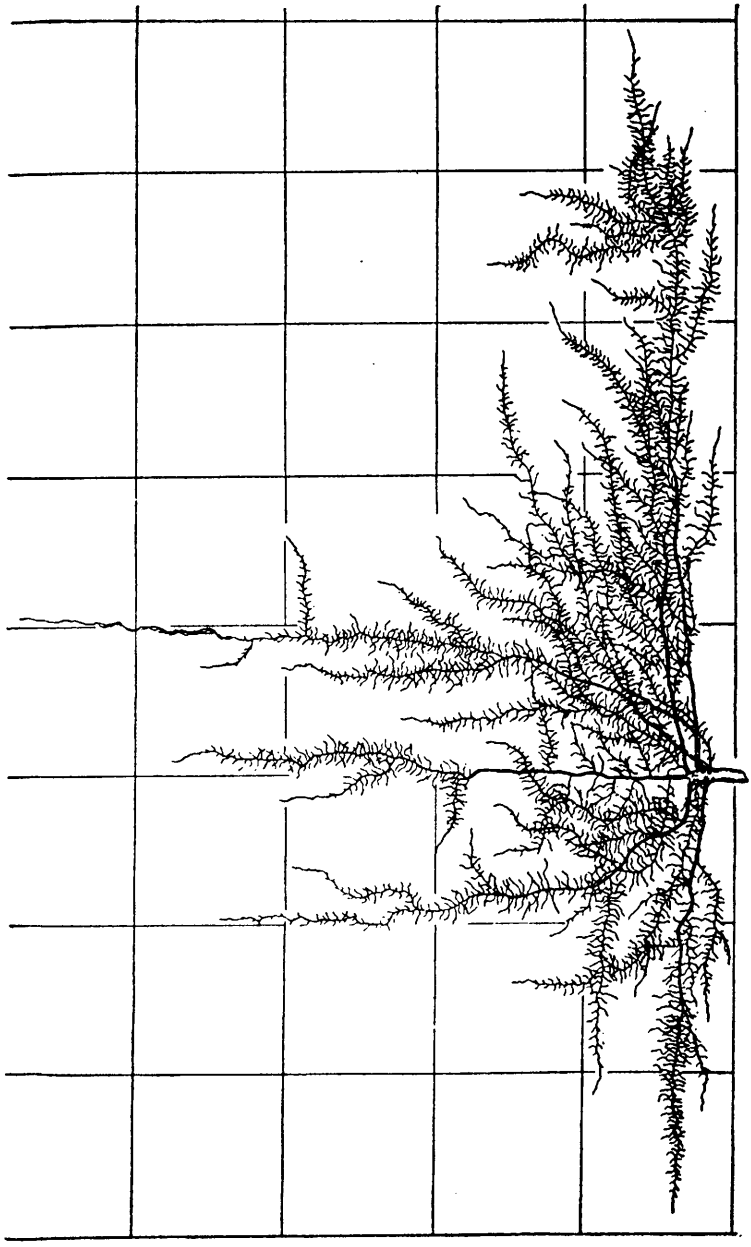

Figure 3. A cross-section of the root system of a cotton plant three and one-half months old. Most of the main roots are shown since they usually develop at right angles to the row as a result of competition with other plants in the row.

further growth being inhibited as a result of competition with those in the adjoining row. They spread more sidely when there is a missing hill or sufficient moisture to reduce competition. They penetrated to a maximum depth of 6 feet. The numerous absorbing roots indicated that considerable moisture was drawn from the subsoil to a depth of 4 feet or more. The finely branched network of absorbing rootlets thoroughly dried the soil from the surface to a depth of 40 inches.

PEANUTS

Peanuts were planted on May 9, 1925. Roots were examined one month later when the plants were 6 inches tall. The root system thoroughly occupied a cone-shaped area of soil which was 16 inches deep and extended 8 inches on either side of the plant. Within this cone-shaped area the soil had been dried out by the numerous absorbing rootlets which were developing on the taproot and its branches. The soil, unoccupied by roots had a water content of 10.8 per cent in excess of the Hygroscopic Coefficient. Samples from the edge of the cone-shaped area where the roots were beginning to penetrate had a water content of 6.1 per cent while near the plants it was only 1 to 2.5 per cent in excess of the Hygroscopic Coefficient.

These cone-shaped root systems consisted of the taproots which penetrated to an average depth of 20 inches and 100 to 145 branches radiating in all directions from it. The average maximum spread was 12 inches. About 4 inches back from their tips absorbing laterals began. Their development resulted in a thorough permeation of the soil and their activities resulted in the development of the cone-shaped area of dry soil.

A second series of excavations was made on July 20. The outline of the root system was still that of a cone. The area completely occupied by the developing roots was now 36 inches wide and 26 inches deep. The distinctly dry condition of the soil occupied by the roots was so noticeable that samples were taken of soil occupied by the roots and from the area free from roots. It was found that at a depth of 14 inches soil free from roots had a water content of 7.2 per cent while that thoroughly occupied had only 1.2 per cent in excess of the Hygroscopic Coefficient.

Excavations made on September 10 disclosed an extensive root system, which completely occupied the first two feet of soil. Numerous roots penetrated the third foot, many of which extended into the fourth foot. The cone-like shape was no longer evident since the symmetrical growth of the roots had been checked by competition with the roots of the plants of the adjacent rows.

ROOT DEVELOPMENT IN 1926

Peanuts of the same variety were used in 1926. Earlier plantings did not thrive well on account of the cold weather, but those planted on April 19 came up quickly and by May 24, they stood 5 to 6 inches high and had eight well developed leaves on the main stalk and branches. About as many more leaves were in various stages of development. The main stem was 6 millimeters in diameter and gave rise to two branches about 2 inches long which were as high as the main stem. The taproot was 3 millimeters in diameter where it joined the hypocotyl. It tapered to 1 millimeter at a depth of 12 inches and to .5 millimeters at a depth of 23 inches where it ended. (Fig. 4). There were 16 branches per inch on the main root near the surface, eight at a depth of 12 inches, four at a depth of 16 inches and none on the last three inches of the root. There were 139 branches on the first foot of the taproot. A maximum spread of 12 inches was recorded. Five roots were observed to turn downward at distances varying from 3 to 6 inches, from the taproot. The remaining thirty which were examined grew in an almost horizontal direction. A

large number of the older develvous, absorbing rootlets were in the process of disappearing.

The main branches were growing perpendicular to the taproot while the laterals were perpendicular to the branches. The larger branches were 1 millimeter in diameter and tapered to .5 millimeters, the laterals were .5 millimeters in diameter. The roots were all quite strong although somewhat fleshy in appearance. The older portions were yellowish in color. Tney grew in a slightly wavy or zigzag manner in the moderately moist, mellow soil.

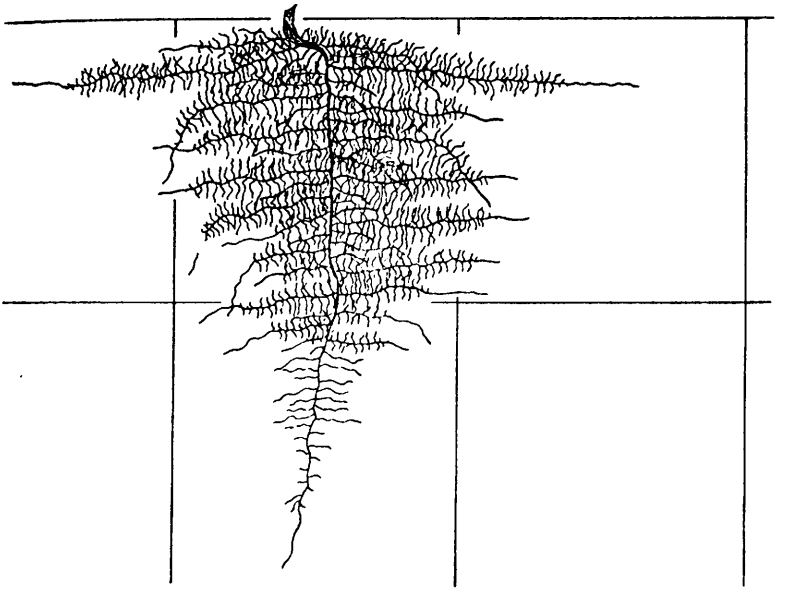

Figure 4. The major portion of a root system of a peanut plant one month old.

The root systems were examined again on June 29. The lateral spread at this time did not exceed 18 inches on either side of the plant. Secondary branches were now much more numerous. Many of the horizontal branches turned downward and were growing parallel to the taproot at various distances from it. The absorbing rootlets had died near the plant on all of the older roots and their yellow, corky covering was quite conspicuous. The laterals from the taproot which bore only absorbing rootlets at the time of the first excavation now had no absorbing rootlets, except near the extremities. A few of the absorbing roots previously observed had grown into permanent roots and were in turn covered with absorbing rootlets. One of the laterals turned downward in case of the plant shown in Figure 5 and reached a depth of 23 inches. This was about a foot less than the depth reached by the taproot.

Some of the other larger branches, which were just beginning to turn downward at the time of the first excavation, now grew in a nearly vertical direction for several inches. In the second foot of soil where the roots forced their way through an unusually hard layer of soil, they pursued a more tortuous course and gave rise to laterals more frequently. This tendency to branch was quite possibly a response to a greater concentration of mineral salts at this level.

The larger branches which were growing in the loose, moist surface soil were supplied near the tips with absorbing rootlets which occurred at the rate of eight to twelve per inch. These absorbing roots were 2 to 4

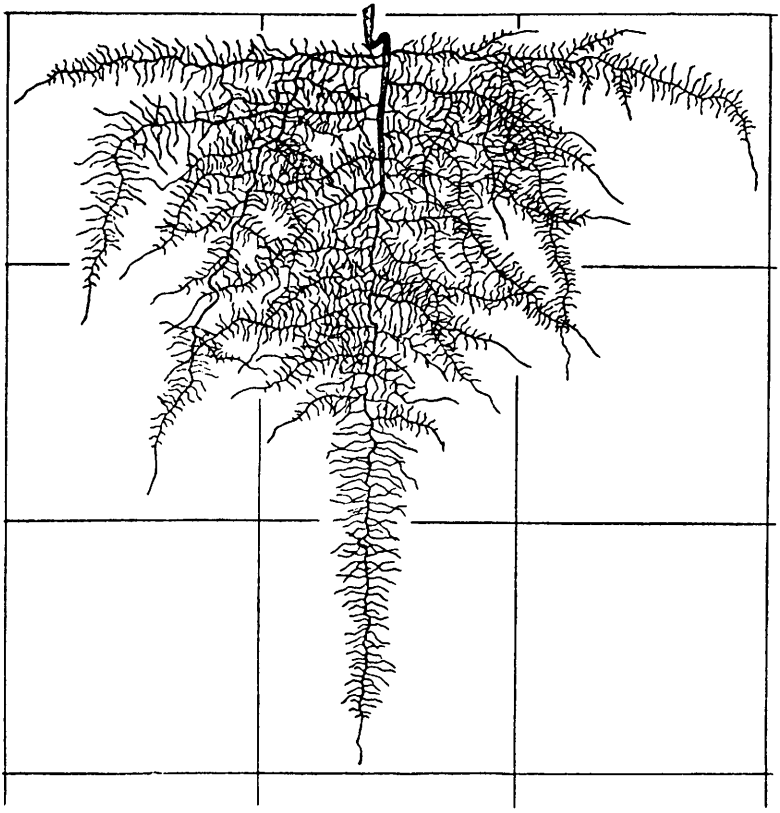

Figure 5. The root syste mof a peanut plant two and one-third months old. Most of the more important roots are shown and the manner of branching is indicated.

inches long where moisture conditions were favorable. They gradually decreased in length to about 2 inches from the tip of the root where none occurred. Here they were replaced by the root-hair zone of the developing root. This zone of absorbing rootlets which occurred just back of the root-hair zone, was about 9 inches in length at this time. When the soil became dry later in the season the older absorbing rootlets died more quickly and the zone of absorbing rootlets became shorter. At times it was only 2 or 3 inches long when the soil was very dry. After rains the zone increased rapidly in length, at the rate of .5 inches or more per day, and the absorbing rootlets became longer. Thus three days after a rain on July 10, the roots showed a marked increase in activity. There were many new absorbing roots .25 inches to 1.25 inches in length. The abundance of absorbing rootlets indicated that the greater part of the absorption was taking place in the first foot of soil. However,

branches were developing rapidly in the second foot. Only the taproot and an occasional lateral penetrated beyond the 2-foot level.

The peanut plants grew rapidly as they normally do at this season and on July 28 the stalks were 12 to 15 inches long. Plants of average size consisted of six strong branches which were still growing and blooming. The branches which were prostrate bore, in the surface loam, five to six dozen peanuts in all stages of development. Each strong plant bore about one dozen full sized peanuts.

The roots of the mature plant were symmetrically branched, yellow in color except in the younger portions, and strong enough to be easily followed in the sandy, loam soil. The taproot branched regularlly at the

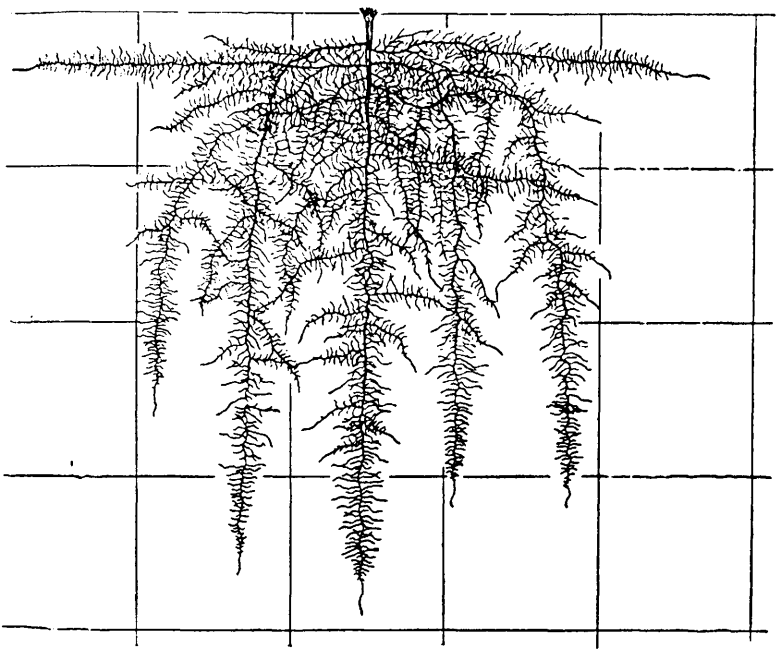

Figure 6. A cross-section of the mature root of a peanut plant showing the important features of the root system.

rate of sixteen branches per inch in the 2 to 8 inch level. Four rows of strong lateral branches began at a depth of 2 inches. These four rows of branches were radially arranged and grew at right angles to the perpendicular taproot. They had developed horizontally for 3 to 18 inches where they turned downward into the subsoil. A few of the longer ones followed a horizontal path throughout their entire length. Occasionally some of them were equal to or longer than the taproot. The taproots characteristically (Figure 6) grew almost directly downward. They tapered rapidly in the first foot of soil, then more gradually to a depth of nearly 4 feet. There was a gradual decrease in the number of branches from sixteen per inch in the first foot of soil to only two to four per inch in the deeper soil layers. Near the tip they were scarcely 1 millimeter in diameter and unbranched. The lateral branches were essentially similar

to the taproot itself. The older portions branched irregularly. The younger portions of the larger branches which were supplied with absorbing rootlets, bore them at approximately the same rate as the taproot. On a root 1.5 millimeters in diameter rootlets occurred at the rate of eight per inch, while on a root 1 millimeter in diameter there were only four per inch. The absorbing rootlets were about .5 of a millimeter in diameter and covered with root hairs.

The first foot of soil was rather thoroughly penetrated by roots at this time but to a lesser degree than in the case of much more vigorous tobacco and cotton plants. Here were found the main roots and their branches which to a large extent penetrated to deeper levels or gave rise to absorbing rootlets only near their extremities.

SUMMARY

The root system of peanuts was symmetrical and regularly branched, and developed in the form of a cone which tapered downward. The cone-shaped outline persisted until competition with nearby plants prevented the continued symmetrical development. At maturity all of the older roots were yellow in color and quite strong. The taproots usually penetrated directly downward to a depth of about 3 feet. The four rows of lateral roots which grow horizontally from the taproot continued in a horizontal direction for several inches, then frequently turn downward for a distance of 2 feet or more. Absorbing rootlets covered most of the root in the second foot of soil when the plants were nearing maturity. This indicated that a great deal of absorption was taking place at this level. Many of the stronger roots were absorbing actively in the moist soil at a depth of 2 to 3 feet.

The extensive development of absorbing rootlets in the first foot of soil, early in the season, indicated that all of the absorption was in this level. The occupation of the second foot of soil and the rapid development of absorbing rootlets in this level during the early summer indicated an increasing importance in absorption from the subsoil. The third foot of soil, also, was of considerable importance in supplying moisture as is indicated by root development there late in the season.

TOBACCO

Tobacco set out during the last week of April, 1925, grew normally. When the plants were one month old the root system consisted of fifteen to twenty white succulent roots which grew in all directions from the taproot. The latter was irregularly branched as a result of being transplanted. These branches were 15 to 20 inches long, indicating a growth of .5 inch or more per day. These roots, except for about 2 inches at the tip, were abundantly supplied with absorbing laterals. The absorbing roots, which occurred at the rate of ten per inch, reached a length of 4 inches on the older portions of the roots. Thus, we have an extensively branched but not very symmetrical root system in the process of development.

The plants were 4 feet tall by July 15, and the numerous, broad, green leaves were in excellent condition. The plants had not reached the stage when the harvesting should be done. The surface foot of soil was thoroughly occupied by roots of all sizes. In fact to a depth of 2 feet there was not a cubic inch of soil observed that was not penetrated by roots. The main roots, which had reached a length of 3 to 4 inches, branched frequently and bore feeding or absorbing laterals which increased in length up to 6 inches. These absorbing rootlets occurred at a rate of four to ten per inch on strong roots. Slender roots bore fewer laterals per inch. The soil was penetrated to a depth of 4 feet.

The root systems of several plants were examined during the last week in August, 1925. The plants had passed the stage when harvesting is done and the leaves were in poor condition. The roots had grown considerably in length, thus increasing the depth and spread of the root system. Excavations in the 5 to 6 foot level revealed only a few delicate roots. Many slender but vigorous roots were found in the 4 to 5 foot level. Within a radius of 2 feet of the plant delicate roots 1 millimeter in diameter penetrated the soil at intervals of 3 or 4 inches. The roots pursued a general downward course and branched frequently. These roots were followed upward. They increased in diameter until at a depth of 3.5 feet the average diameter was 1.5 millimeters and at 2½ feet the main roots were 2 millimeters in diameter. The number of roots increased in the soil and here many vigorous branches well supplied with feeding laterals occurred. The first 2 feet of soil was filled with roots of all sizes. Some of the larger ones had a diameter of 1 centimeter near the plant.

ROOT DEVELOPMENT IN 1926

The experiments were repeated in 1926 and in general the root behavior was found to be similar to that of 1925. Root drawings were made both years, but only those made in 1926 were used for illustrations. Thrifty tobacco plants were set out on April 12. They grew rapidly and on May 15, had about six fair sized leaves, the largest were about 10 inches long and 5 inches wide. The stems had not yet begun to elongate.

The main taproot was ⅜ of an inch in diameter at the crown but after 2 inches broke up into seventeen small roots which had diameters of 1 to 3 millimeters. One root 3 millimeters in diameter angled downward slightly and tapered to 1 millimeter at a distance of 17 inches from the plant. Near the plant laterals 1 to 4 inches long and .5 to 1 millimeter in diameter, occurred at the rate of eight to twelve per inch. Laterals 1 to 2 inches long and .5 millimeter in diameter occurred 12 inches from the plant at the rate of two per inch. The last 2 or 3 inches of the roots were unbranched. This root system was typical for tobacco. Rather strong, fleshy, roots maintained a diameter of 1 millimeter to the tip branching fairly regularly. Strong laterals developed on them which gave rise to the sub-laterals as soon as they were an inch or two in length. Four roots of the eight examined penetrated the second foot of soil, the maximum depth of penetration being 20 inches.

The first 6 or 8 inches of the main roots were yellowish; the smaller roots were white. This yellowish portion was made up of mature tissues and functioned in supporting the plant and conduction. A transition zone, from the mature to the actively-absorbing portion of the main root, occupied about 4 more inches. In this portion of the root there was a gradual change from the mature yellowish region to the white succulent distal part which was covered with root hairs and constituted a portion of the absorbing system of the plant. They grew fairly straight except for a waviness characteristic of many roots and an occasional sharp turn to avoid some obstacle. One root followed a root cast downward for 9 inches and another followed an earth worm burrow for several inches. A root system representative of this stage of development is shown in Figure 7.

The plants were considerably taller and were supplied with larger and better developed leaves by June 14. Some of the lower leaves had died and had been replaced by younger ones which were in vigorous growing condition. The depth and spread had increased only about 1 foot but the development of numerous branches had added greatly to the com-

plexity of the root system. In all parts there was indication of great root activity. All but the older portions of the larger roots were white,

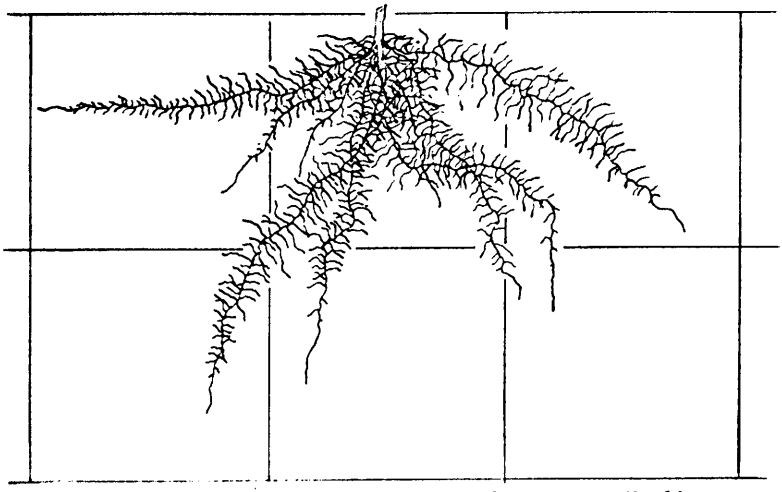

Figure 7. The root system of a tobacco plant one month old.

succulent and covered with root hairs. The general features of the root system at this time are shown in Figure 8.

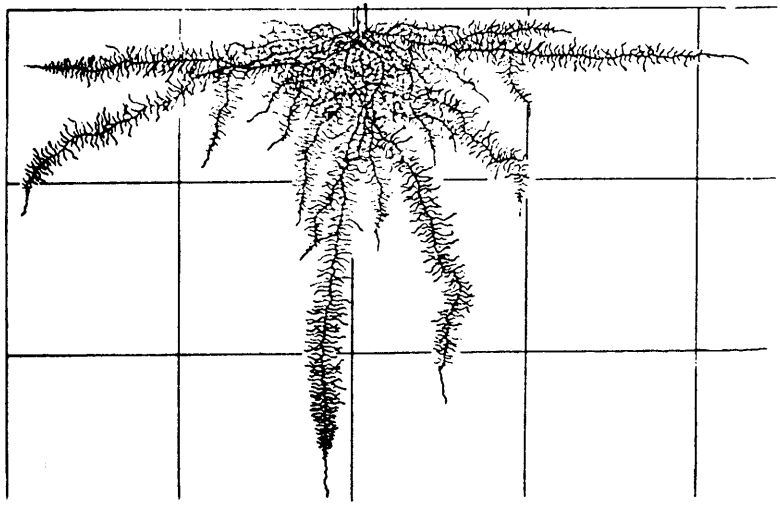

Figure 8. A sectional view of the root system of a tobacco plant two months old.

The root systems of tobacco were fully developed by July 27. The largest and best leaves had just begun to die and suckers were develop-

ing along the stem. The root systems were somewhat more extensive than they would be in plants suitable for harvesting.

The root systems are here described as the roots were excavated. A representative system is shown in Figure 9. Near the bottom of the trench only tender white unbranched roots 1 millimeter in diameter were found. This was at a depth of 4.5 to 5 feet. From 4 to 4.5 feet the longer roots were branching freely in the moist soil. This portion of the root was young and the branches were only .5 to 2 inches long and had a diameter of .5 millimeter. Above this at a depth of 3 to 4 feet the larger roots were slightly yellowish in color and were 1.5 millimeters in diameter. Here the laterals were longer and occurred at the rate of eight per inch. The oldest were 3.5 inches in length and were beginning to rebranch. At a depth of 2 to 3 feet, the roots, for the most part, pursued a general downward course. This was true of the deeper levels also. The diameters of these older portions of the roots had increased with age up to 2 millimeters. Branches from the main roots had increased in length and complexity in proportion to their age. Some of them were 2 feet long and abundantly branched.

The horizontal roots were much longer at a depth of 1 to 2 feet. Strong yellowish roots with diameters up to 5 millimeters were common. Laterals grew in all directions from them, but for the most part either horizontally or downward. Some of the longest of the branches started at a depth of 12 to 14 inches and followed a general downward course to a depth of nearly 4 feet. The number of laterals on these longer roots had also increased and frequently numbered twelve per inch. The majority of them were short absorbing roots 2 to 4 inches in length. A portion of them had increased in length and diameter and had become a part of the permanent root system of the plant.

The largest roots in the surface foot of soil were 20 millimeters in diameter. Some of them broke up almost immediately into smaller roots which branched and gave rise to numerous absorbing rootlets. Others grew outward or downward 2 or even 3 feet before giving rise to many laterals. The longer roots did not give rise to absorbing laterals near the plants. Here the absorbing roots were all branches of the third or fourth order. The absorbing roots shown in Figure 7 and Figure 8 had, by this time, ceased to function and had for the most part entirely disappeared. The function of absorption had been taken over by new absorbing roots on the new portions of the root system.

Root systems developing from the transplanted tobacco had no taproot and the symmetry characteristic of cotton and peanuts previously examined was lacking. Root branches developed from transplanted portion of the original root system and grew at all angles from the base of the plant. Some followed a horizontal course in the moist surface loam but some grew directly downward or at more or less of an angle. Competition among the horizontal roots caused them to develop less strongly at the extremities as the season progressed. The competition stimulated the development of their longer branches some of which penetrated downward and not infrequently the branch became the main root later in the season. Thus many roots which appeared to turn rather sharply downward about 2 feet from the plant were not the result of curvatures of the original root but were developed from a portion of a horizontal root and one of its lateral branches. This occurred where the distal portion of the horizontal root ceased to function or became unimportant as an absorbing structure.

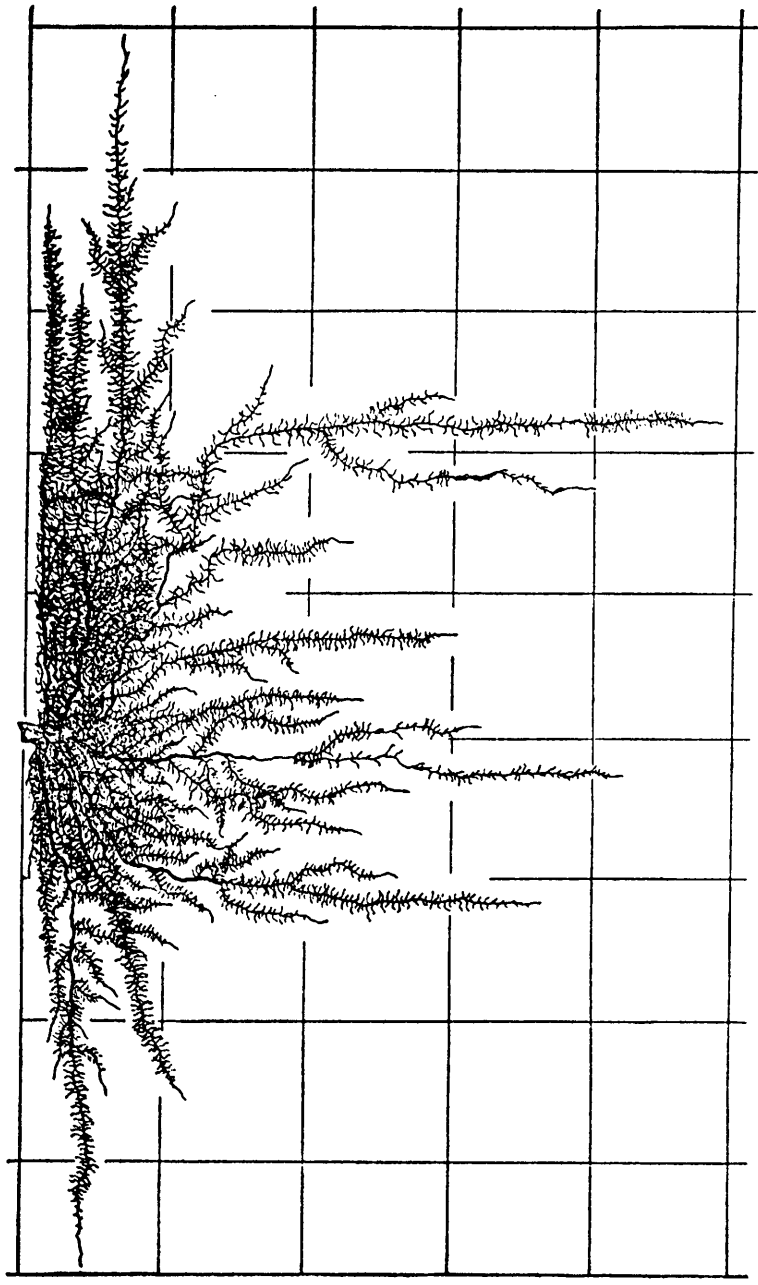

Figure 9. A sectional view of the root system of a three-and-one-half-months old tobacco plant showing the main branches and numerous smaller ones.

SUMMARY

The root systems of peanuts and cotton are regularly branched and symmetrical. The root system of tobacco lacks symmetry because of transplantation.

All of the root systems were alike in the following respects:

The main or taproot is the first structure of the seedling to develop. Absorption begins at first through the epidermis but soon rapidly increases since root hairs appear while the root is only a fraction of an inch long.

Branches appear while the root is still only a few inches long. The branches in turn are soon covered with root hairs, and absorption is greatly increased.

The main or taproot and its branches develop in the form of a more or less symmetrical cone which increases in size as the roots develop.

As the soil is dried out and the roots continue to grow the majority of the older absorbing rootlets die and absorption is carried on by the younger rootlets.

Those which do not die increase in length and usually in diameter and become permanent roots.

The immediate environment determines just which of the rootlets will become permanent roots.

The older portions of the roots do not absorb directly and frequently bear no absorbing rootlets. They may be reinvested with absorbing rootlets if the soil moisture is replenished.

The development of new absorbing rootlets is more characteristic of tobacco while in cotton and peanuts active terminal growth of both main and branch roots results from additional moisture.

The absorbing portions of the root system is larger during moist periods owing to an increase in the number and length of absorbing rootlets.

The absorbing portion of the root system decreases during periods of drouth owing to the fact that the temporary or deciduous absorbing rootlets die much more rapidly than they are produced.

Competition with roots of plants in adjacent areas check the lateral spread of the horizontal roots. This is due, in part at least, to the drying of the soil. This causes most of the main roots to develop in a plane perpendicular to the row.

There is a greater tendency for the roots to intermingle if the soil is kept moist as in periods of frequent precipitation.

The lower level at which active absorption takes place increases in depth from the surface foot in early summer to a depth of 3 to 6 feet near the end of the growing season. This is indicated by the presence of absorbing rootlets covered with root hairs.